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TECHNICAL REPORT

REPORT OF DROP TEST CONTAINER OFFSHORE TRANSFER SYSTEM (COTS)

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NAVAL WEAPONS STATION EARLE
Colts Neck, New Jersey 07722

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When a Crane-on-Deck (COD) or Temporary Container Discharge Facility (TCDF) is used to transfer containers from a containership to lighters alongside, the possibility of damage to the container and its contents always exists because of relative motions and pendulation. A series of tests was conducted to assess the container's structural limits and the shock levels imparted to the container and its contents as a result of the impact. During testing the containers were dropped from heights

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REPORT OF DROP TEST CONTAINER OFFSHORE TRANSFER SYSTEM (COTS)

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EXECUTIVE SUMMARY

PURPOSE

When a Crane-on-Deck (COD) or Temporary Container Discharge Facility (TCDF) is used to transfer containers from a containership to lighters alongside, the possibility of damage to the container and its contents always exists because of relative motions and pendulation. A series of tests was conducted to assess the container's structural limits and the shock levels imparted to the container and its contents as a result of the impact. During testing the containers were dropped from heights, which had been calculated to provide representative impact velocities onto a concrete pad, and the appropriate data recorded. Additional tests included drops onto a resilient foam surface in order to evaluate the effectiveness of passive shock mitigation.

PROCEDURE

Three different types of containers were tested [steel, aluminum and fiberglass reinforced plywood (FRP)], in a horizontal and an oblique (corner lands first) attitude at different heights resulting in impact velocities of 4, 6, 8 and 10 feet per second (fps). In a Sea State 3, which represents the operational limit for COTS, there is a possibility of impact velocities up to 10 fps during container offloading. NWHC Earle conducted 44 container drops using empty containers and containers at various weights. Concrete deadloads were used to simulate cargo with gross weights of 25,000 pounds and 44,000 pounds.

Container degradation and damage was assessed visually. Six accelerometers located on two diagonally opposite lower corner post fittings and on the concrete deadloads (two on palletized deadloads, two on deadloads laid bare on the container floor) were used to measure levels on the container and its contents. The accelerometer data from the bare surface was compared to the accelerometer readings from the drop tests onto the padded surface to assess the shock mitigation properties of a resilient foam with a density of 9 pounds per cubic foot (PCF).

The steel container was tested and sustained sufficient damage from a series of empty and half load tests conducted at velocities of 4 to 10 fps to exclude it from full load tests. It was then determined that a single container could not survive a full test syllabus. Accordingly, the aluminum and the fiberglass reinforced containers were tested at only full load configuration at both flat and oblique attitudes. The aluminum container was tested at impact velocities of 6 and 10 fps on both surfaces and the FRP container was tested only at impact velocity of 10 fps on the bare surface.

FINDINGS

1. Although the steel container could not survive the complete test syllabus, it is anticipated that it would have survived a test with full load configuration at impact velocity of 10 fps if previous drops had not been conducted.

2. The aluminum and FRP containers survived drop tests in full load configuration with impact velocities of 10 fps.

3. Peak G's imparted to the container upon impact increased with velocity.

4. Foam padding reduced shock levels to the container by at least 50% in most cases.

5. Foam padding did not reduce shock levels to the concrete deadloads.

6. Deadloads on pallets experienced essentially the same G-levels as deadloads on bare container flooring.

7. Oblique angle drops (corner lands first) resulted in higher peak G levels than flat drops.

8. Pallets sustained considerable damage as a result of the drop(s).

CONCLUSIONS

1. Container life is dependent on the cumulative effect of impacts.

2. Foam padding will increase container life by decreasing shock levels to the container.

3. Foam padding used in the tests was too stiff to afford protection to the deadloads. Subsequent investigation revealed that a foam with a density of 4 pcf may afford protection to the contents as well as the container itself.

4. Container floor deflection and/or deformation causes a decrease in shock levels imparted to the deadloads.

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INTRODUCTION

DOD planning for the logistics support required to sustain major contingency operations, including amphibious assault operations and Logistics-Over-the-Shore (LOTS) evolutions, relies extensively on the utilization of U.S. Flag commercial shipping. Since the mid 1960's commercial shipping has been steadily shifting towards containerships, Roll-on/Roll-off (RO-RO) ships and barge ships (e.g., LASH, SEA-BEE). By 1985 as much as 85% of U.S. Flag sealift capacity may be in container ships - mainly nonselfsustaining (NSS) containerships. Such ships cannot operate without extensive port facilities. Amphibious assault and LOTS operations are usually conducted over undeveloped beaches and expeditious response times preclude conventional port development. Handling of containers in this environment presents a serious problem.

The problem, as defined above, is addressed in the overall DOD Over-the Shore Discharge of Cargo (OSDOC) efforts involving developments by the Army, Navy and Marine Corps. Guiding policy is documented in the "DOD Project Master Plan for Surface Container Supported Distribution System" and the OASD I&L system definition paper "Over-the-Shore Discharge of Cargo (OSDOC) System."

In response to the DOD Master Plan, Navy Operational Requirement (OR-YSL03) has been prepared for an integrated Container Offloading and Transfer System (COTS) for discharging container capable ships in the absence of port facilities. The COTS Navy Development Concept (NDCP) No. YSL03 was promulgated July 1975 and the Navy Material Command tasked with development. The Naval Facilities Engineering Command has been assigned as Principal Development Activity (PDA) with the Naval Sea Systems Command assisting. The COTS advanced development program includes the ship unloading subsystem, the ship-to-shore subsystem and common system elements. The ship unloading subsystem includes:

1. The development of Temporary Container Discharge Facilities (TCDF) employing merchant ships and barges with add-on cranes and support equipment to offload nonselfsustaining (NSS) containerships alongside.

2. The development of Crane-on-Deck (COD) techniques and equipment for direct placement of cranes on the decks of NSS containerships to render them selfsustaining in an expedient manner.

3. The development of equipment and techniques to offload RO-RO ships offshore.

4. The development of interface equipment and techniques to enable ship discharge by helicopters (either existing or projected in other development programs).

The ship-to-shore subsystem includes the development of elevated causeways to allow cargo handling over the surfline and development of self-propelled causeways to transport cargo from ships to the shoreside interface. Support subsystems include:

1. The development of wave attenuating Tethered Float Breakwaters (TFB) to provide protection to COTS operating elements.

2. The development of special cranes and crane systems to compensate for container motion experienced during afloat handling.

3. The development of transportability interface items to enable essential outside COTS equipment transport on merchant ships - particularly bargeships.

4. The development of system integration components such as moorings, fendering, communications and services.

This report addresses the progress and accomplishments associated with the allowable container impact velocity and shock mitigation phase of the relative motion compensating crane on deck subsystem.

One of the lessons learned during the OSDOC evaluations is that in a Sea State 2 and above, considerable difficulty can be expected when attempting to place a container in the receiving vessel. This is due to the pendulating motions of the container induced by the containership responding to the Sea State, and the impact of the container on the receiving vessel's deck because of the relative motions between the container and the lighter.

Development of active motion compensating cranes and passive shock mitigation systems to minimize the effect of relative motions is contingent upon ascertaining data regarding survivability of intermodal containers under rough handling situations. Present standards influencing the design and construction of intermodal containers do not address the severe dynamic situation which exists in the COTS environment. Therefore, the Naval Weapons Handling Center was tasked to perform a series of tests designed to establish performance envelopes for a number of commercial intermodal containers under various conditions of container gross weight, impact velocity and impact attitudes. In addition, data relevant to commodities in the container was to be obtained. All of this information would be provided to the COTS program manager for use into determining the need for and extent of motion compensation.

This effort also includes evaluating the performance of a passive shock mitigation system consisting of polyethylene foam pads as the cushioning media.

BACKGROUND

As part of the overall military containerization program, the Container Off-Shore Transfer System (COTS) is intended to provide the link between container-supply ships and established beachheads. One of the problems associated with this phase is the unloading of containers from the mother ship to barges or lighters which would be tugged to floating docks, causeways, or the beach where the containers would again be transferred to trucks for inland delivery. The barge loading must be accomplished in a variety of Sea States, and to com-

pensate for the relative motion between containerships and barges, sophisticated motion compensating cranes may need to be developed. However, crane operating parameters have not been fully established because of limited information regarding structural characteristic of intermodal containers when subjected to impacts such as those which might occur when transferred to a barge and lighter in motion due to wave action. The concern is that operating speeds of the crane and pitching movements of the barge may combine to result in container impact velocities which would be destructive to either the container or its contents. Accordingly, structural integrity of commercial intermodal containers needs to be fully established in terms of what contact velocities can impact be withstood without exceeding some criteria for damage. In addition, crane parameters need to be examined to determine what is commercially available, operating speeds, capacities, reach, etc., so that performance envelopes of both containers and cranes may be compared in order to derive a compatible system.

Funded by the Naval Ships Research and Development Center, Annapolis, Maryland in June 1975 the Naval Weapons Handling Laboratory, WPNSTA Earle, Colts Neck, New Jersey initiated a preliminary test program to determine commercial intermodal container performance limits. Using 8'x8'x20' aluminum containers procured from the Strick Corporation, drop tests were conducted at heights necessary to attain nominal impact velocities of 4, 6, 8 and 10 feet per second. The tests were conducted with the container(s) in a flat attitude and in an oblique attitude (container suspended with one corner low prior to release). The oblique test is considered to be more representative of the impacts a container would be subjected to during transfer to a barge or lighter in rough seas than the conventional rotational drop tests normally used in container testing. Also, three weight conditions were selected for these tests; empty (5,000 pounds), 1/2 loaded (25,000 pounds) and fully loaded (45,000 pounds). Palletized inert MK 82 Bombs were used as weights used during these tests. A single tier of 10 pallet loads was used for the 1/2 load and a double tier for the full load tests. The criteria to assess whether or not "failure" has occurred was predicated upon one or both of the following conditions:

<u>Contents</u>

Disintegration of unit loads of ordnance such that exposed ammunition is free to move about the container.

A dunnage failure such that unit loads of ordnance have shifted sufficiently to preclude unloading with conventional handling equipment.

<u>Containers</u>

Distortion or destruction of the container of a magnitude that prevents further handling.

Distortion or damage to the container sufficient to prevent the door from being opened and unloading operations from being conducted.

Empty, 1/2 load and full load tests have been completed for both the flat and oblique container drop attitudes. Although some local failures occurred, i.e. rivet failures, some distortion of container floor frames, and other minor damage, no failures as defined by the foregoing criteria occurred. Although some of the tests were conducted with accelerometers and strain gages, visual observations were the dominant method of assessing container survival of the drop tests.

TEST PROGRAM

1. General

Results of the preliminary test program indicated that further tests, using a cross-section of commercially available intermodal containers, were necessary. Accordingly, a subsequent test program, funded by the Naval Coastal Systems Center, Panama City, Florida, was planned. The container survivability study seeks to determine performance limits for a variety of commercial intermodal containers. As indicated earlier, internationally accepted standards determine such parameters as container size, handling interface, ability to withstand certain types of performance testing, and others. However, none of the requirements address ultimate container strength in terms of container impact velocity. The test program, herein described, was planned to provide that information by a series of drop tests conducted with the acquired containers at varying weights and drop attitudes. The drop heights were increased to permit the containers to impact at greater impact velocities up to the point of container failure or 10 feet per second (fps), whichever occurred first.

The decision to limit tests to 10 fps was predicated upon two factors. First, experience gained from earlier testing indicated that at least one type of commercial intermodal container was capable of withstanding 10 fps impacts without structural degradation to the extent which precluded further handling of the containers or removal of its contents. Second, the relative motion between containership and the receiving lighter in a Sea State 3 results in a potential impact velocity of about 6 fps for a container suspended in a fixed position relative to the crane boom tip (i.e., zero cable payout). According to the findings reported in "Mobile Crane Data Summary for Container Offloading and Transfer System" cargo cranes of the type which would be used aboard containerships in a COTS operation are all controllable to provde a payout speed of less than 4 fps. Therefore, the potential to land containers on the deck of a ligher at velocities less than 10 fps presently exists. To conduct impact tests in excess of 10 fps was considered to be an unwarranted punishment of the containers.

Data obtained during the test consisted of both instrumented accelerometer readings and high speed motion picture coverage to aid in the determination of impact velocities of the corner diagonally opposite the end at impact during corner drop tests. Container damage was assessed visually.

Analytical comparison of impact velocity, freefall versus tethered, is described in Appendix B.

2. Equipment

a. Containers

The containers used during these tests were 8'x8'x20' commercial intermodal containers as indicated in Table I. All were constructed in compliance with International Standards Organization (ISO) requirements. However, the material and method of assembly was different.

TABLE I

Intermodal Containers Procured for Container Survivability Study

Manufacturer	Description	Cost
Seaguard Corporation	8'x8'x20' Closed Container - All Steel Construction	$2,485.00
Theurer	8'x8'x20' Closed Van - Fiberglass Reinforced Plywood Panels with Steel Top and Bottom Frames	$4,000.00
Theurer	8'x8'x20' Closed Van - Aluminum Panel Over Steel Frame Plywood Sheathed Walls	$3,400.00

b. Hoisting Equipment

(1) Lift Tower

The drop tests were conducted beneath a test tower used normally for testing slings, strongbacks and other similar handling equipment. Total capacity of the tower (Figure 1) is 80,000 pounds. Clearance dimensions between tower supports is approximately 10 feet wide by 20 feet high.

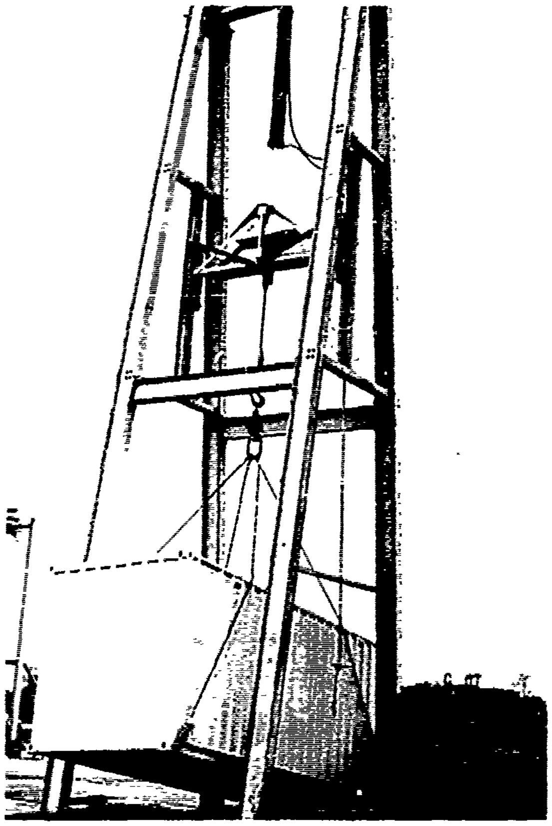


Figure 1 - Test Tower (Capacity 80,000 Pounds)

(2) Slings

Two four-legged wire rope slings were fabricated to facilitate these tests. One sling had legs of equal length and was used for flat drops. The second sling was configured with legs of unequal length to result in the container assuming an oblique attitude when elevated. This attitude resulted in an approximate angle of 7° between the horizontal plane of the impact surface and a diagonal drawn along the container floor from the low end of the container to the high end when in the elevated position (Figure 2). Each leg of the sling was attached to the container lower corner lifting fittings, while the opposite end was attached to a quick release mechanism (NSN 1670-00-434-5782; coupling, extraction, force transfer, air drop) which is rated at 60,000 pounds (Figure 3).

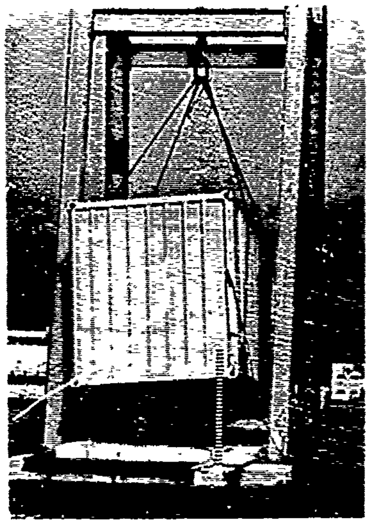


Figure 2 - Container Positioned In Oblique Attitude 7^{o} Angle

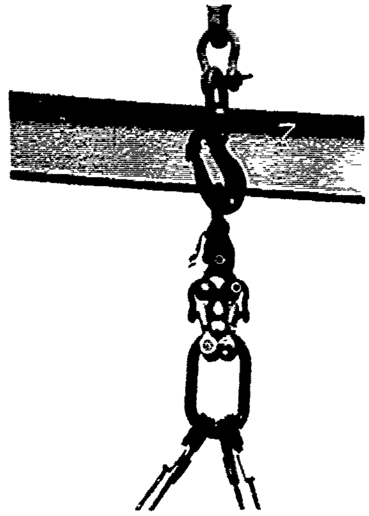


Figure 3 - Quick Release Mechanism (60,000 Pound Rating)

c. Test Loads

The loads used during these tests were fabricated from concrete with built in capability for forklift truck and sling handling. The design also provided for interlocking the loads in a stacked configuration (Figure 4). Each separate block nominally weighed 2,000 pounds and was approximately 40 inches wide by 40 inches long and 18 inches high. Figure 5 shows the double tier configuration.

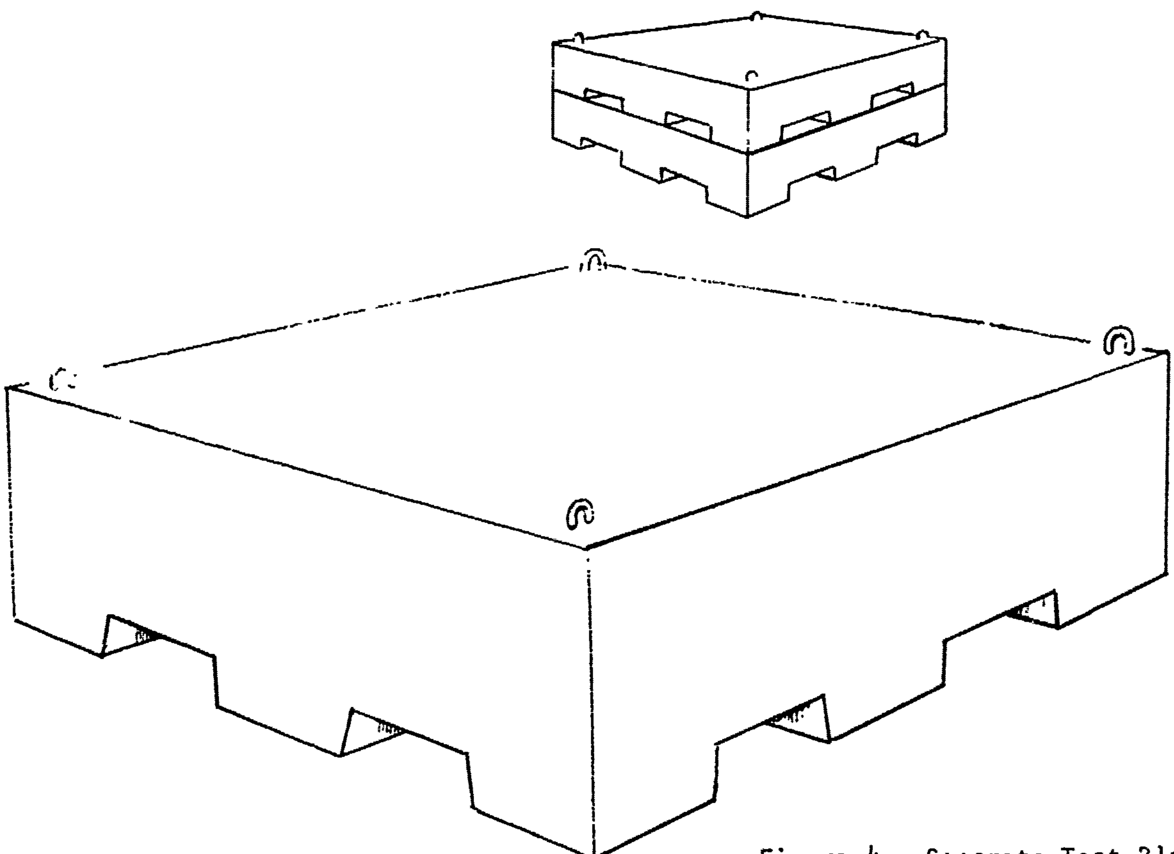


Figure 4 - Concrete Test Block (2,000 Pounds)

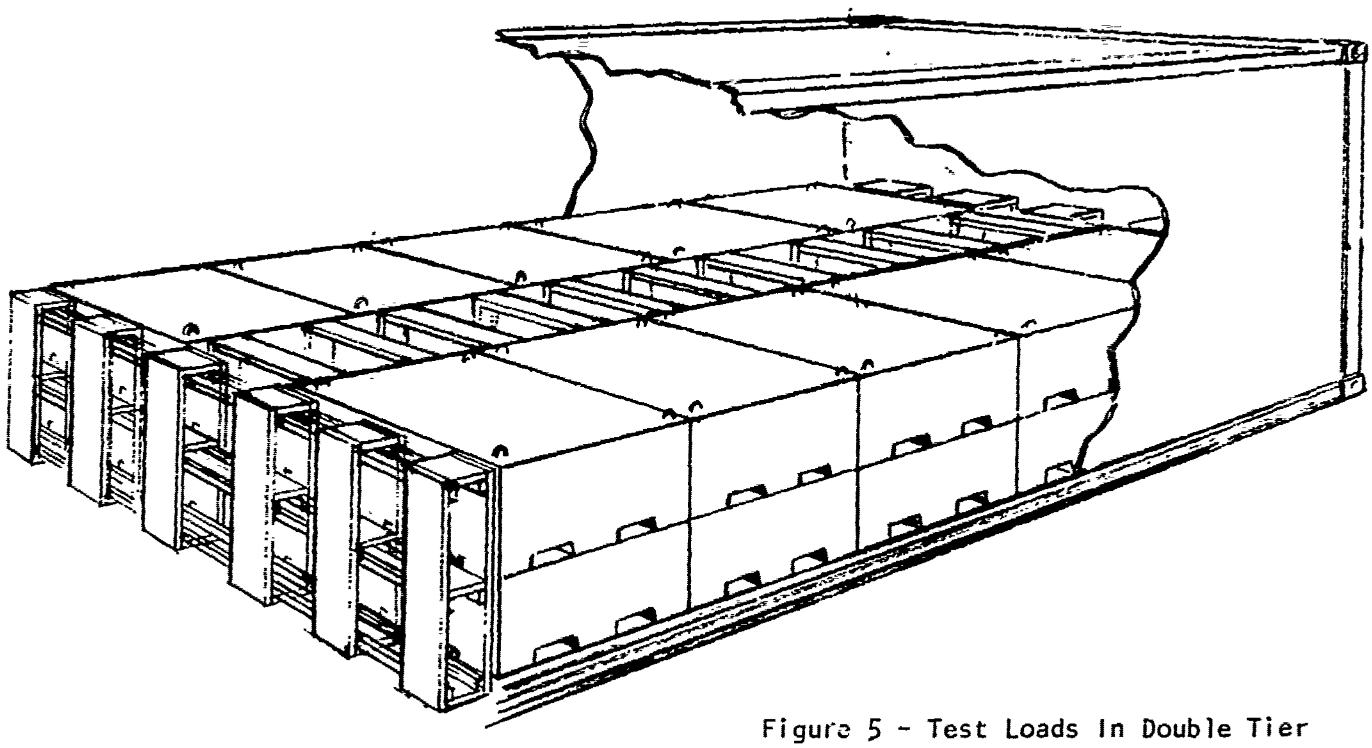


Figure 5 - Test Loads In Double Tier Configuration

The test loads were placed in the container bare on the container floor with the exception of loads which laid on wooden and steel pallets respectively to assess possible shock mitigation by the pallets. Wood dunnaging and barriers were not made to duplicate or to conform to any standard but followed generally accepted practices.

3. Impact Area

The impact area consists of a reinforced concrete slab 24 inches thick covered by 1/2-inch steel plates. The surface is considered to be unyielding (Figure 6).

4. Shock Mitigation Material

Pads of closed cell, 9-pound density polyethylene foam 6 inches thick were used during the tests to ascertain the passive shock mitigating potential of this material for the COTS program. Each pad was 19 inches by 9 feet and sufficient quantities were obtained to completely cover the container impact area (Figure 7).

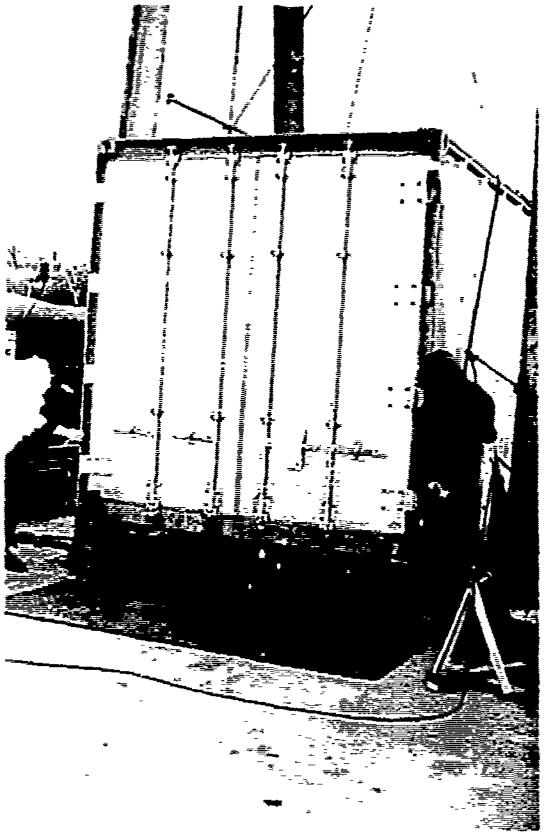


Figure 6 - Aluminum Container Prior To Flat Drop On Steel Plated Unyielding Surface

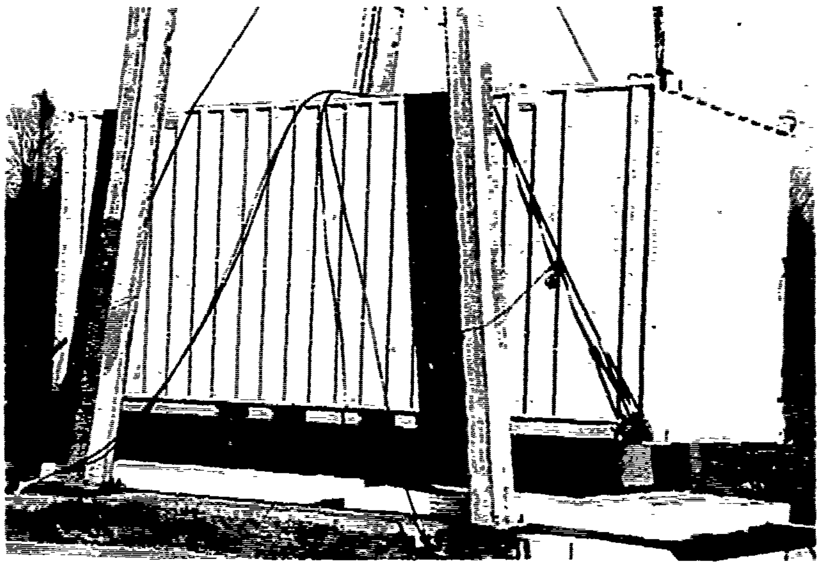


Figure 7 - Steel Container Prior To Flat Drop On Padded Surface

TEST PROCEDURE

The test procedure was planned to subje‹: each container to four series of drops at empty, half load and full load conditions. The series were:

1. Flat Drop on Bare Surface

2. Flat Drop on Foam Cushioning

3. Corner Drop on Bare Surface

4. Corner Drop on Foam Cushioning

The intent of the test program was to determine the containers' resistance to structural damage by incrementally increasing the velocity of impact by free fall dropping the container from increasing heights. However, it is noted that the free fall condition does not fully represent the real situation. It should be recognized that the motion would be a function of relative motion between vessels and crane payout velocity. For the sake of simplifying the analysis, this report will assume that for flat impacts there is no rebound of the container, and that for oblique impacts, the container center of gravity does not change in velocity from the time of initial contact to the time that the remainder of the container impacts. This situation is illustrated in Figure 8.

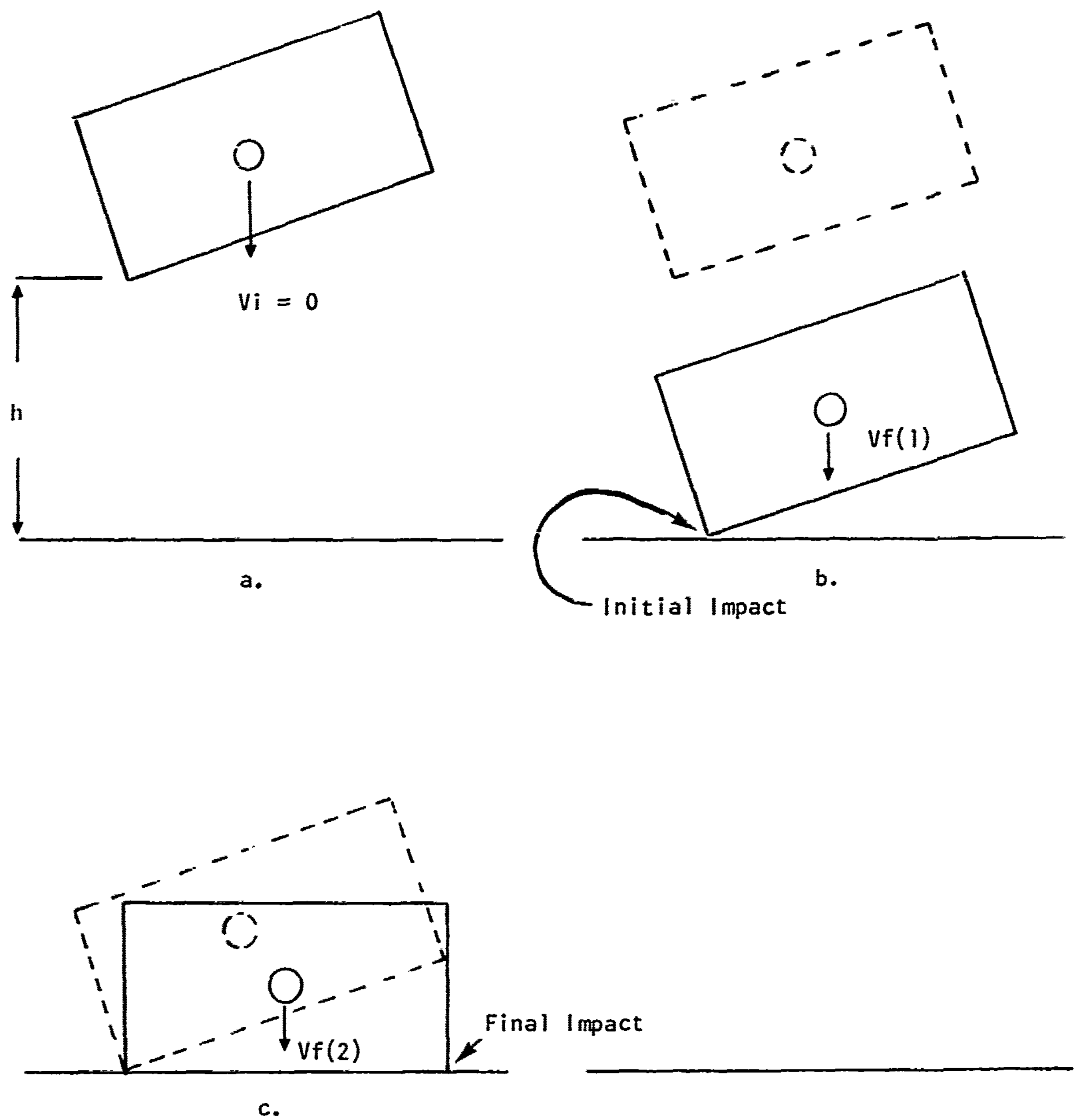
Under the condition demonstrated in Figure 8, the velocity of the initial impact point goes to zero, but the diagonally opposite end is bound by V end = 2V.

The situation is contrasted to the free fall drop tests to which containers involved in this test program were subjected. In the free fall situation the container may impact initially on a corner at some initial velocity (Vi), however, the center of gravity continues to accelerate an‹ 'arly and is affected by the moment of inertia of the container, lius of gyration, etc. Appendix C contains the analysis relevant this motion.

It is important to note that there is a difference between the container impact velocity in the free fall condition, as tested, and that which would occur in the COTS scenario. Figure 2 of Appendix B shows this relationship.

The steel container was first tested in an empty load configuration using only the accelerometers located on the diagonally opposite lower corner post fittings. It was tested in this empty load configuration on both padded and nonpadded surfaces; at oblique and flat attitudes; and at initial impact velocities of 4, 6, 8 and 10 fps. No damage to the container was noted during the empty tests.

The steel container was then subjected to 1/2 load tests (20,000 pounds) on a padded surface at a flat attitude. Impact velocities of 4, 6, 8 and 10 fps were attained. The first damage to the container



Legend: a = Container approaching impact
b = Velocity at initial impact
c = Vi
h = Initial Height of Container

Note: Vi remains constant until the remainder of the container impacts with the deck.

Figure 8 - Velocity of Container c.g. at Final impact Vf(2) Assumed to Equal Velocity at Initial Impact Vf(1) During Oblique Tests

was noted on the 10 fps drop, consisting of slight side rail and cross member deformation (Figure 9). The steel container was then tested at 1/2 load at an oblique angle on the padded surface at impact velocities of 4, 6, 8 and 10 fps.

At 8 fps a substantial increase in damage was noted and floor breakthrough occurred (Figure 10). However, the damage done was not enough to exclude it from further testing as set by the criteria on page 14.

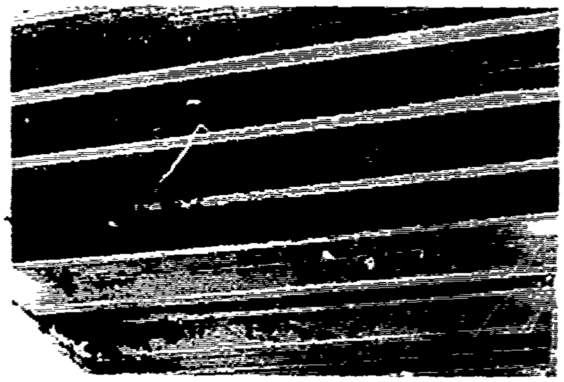


Figure 9 - Minor Side Rail and Cross Member Deformation (Steel Container)

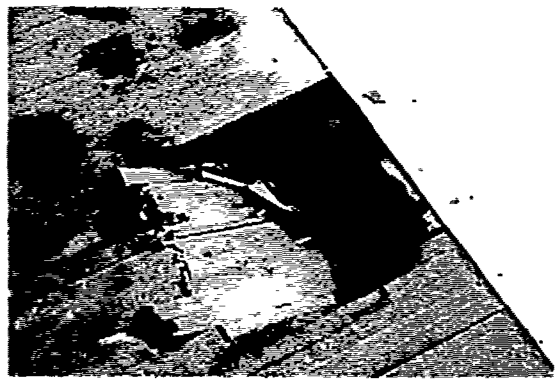


Figure 10 - Floor Breakthrough (Steel Container)

Accordingly, the steel container was tested at 1/2 load at the impact velocities of 4, 6, 8 and 10 fps on the bare surface in both flat and oblique attitudes with no significant relative increase in damage. At that time it was determined that the steel container could not survive the full load testing due to the cumulative effect of the drops. However, it is reasonably fair to assume that the steel container would have been able to survive a full load drop at an impact velocity of 10 fps had not the previous drops been made.

As a result of the steel container testing it was deemed that a single container would not be able to survive a complete test syllabus (Figures 11 and 12). Therefore, it was decided that the aluminum container would only be tested at 6 and 10 fps in a full load configuration on both surfaces and in both attitudes.

At the end of this foreshortened test syllabus, damage to the aluminum container was slight. Damage consisted of "I" beam cross member flange deformation, fork pocket weld crack and some minor floor damage (Figures 13 and 14).

The fiberglass reinforced container was tested twice in full load configuration on the bare surface in a flat and oblique attitude. Damage was restricted to the wood flooring. There was no damage to the frame (Figure 15).

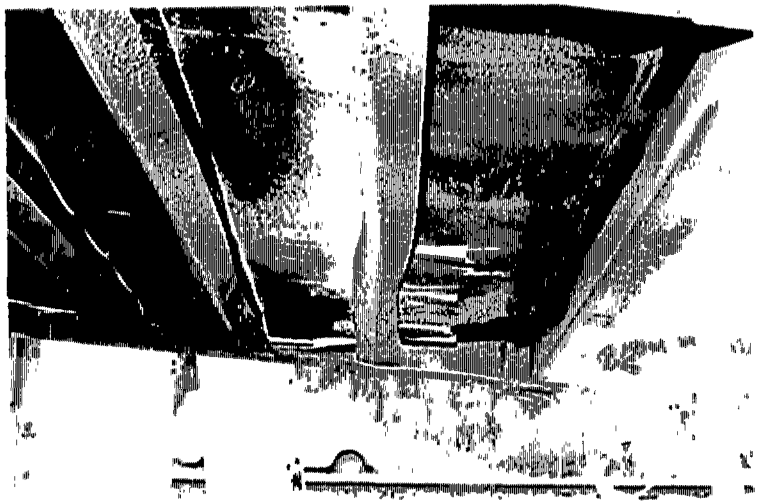


Figure 11 - Flooring Failures On Steel Container

Figure 12 - Severely Deformed Channels Due To Extensive Tests

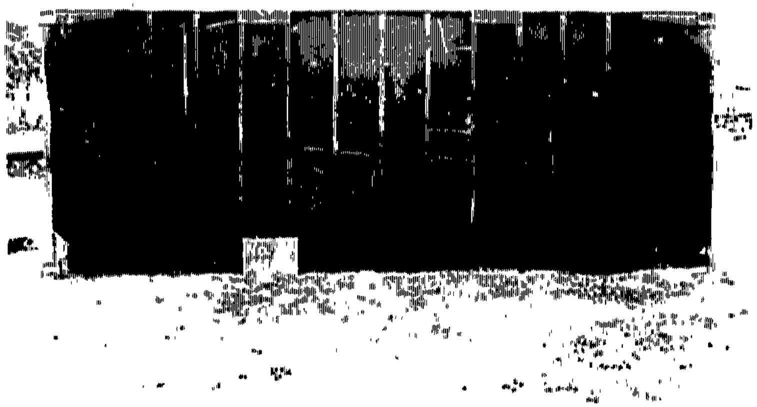


Figure 13 - Aluminum Container After Testing

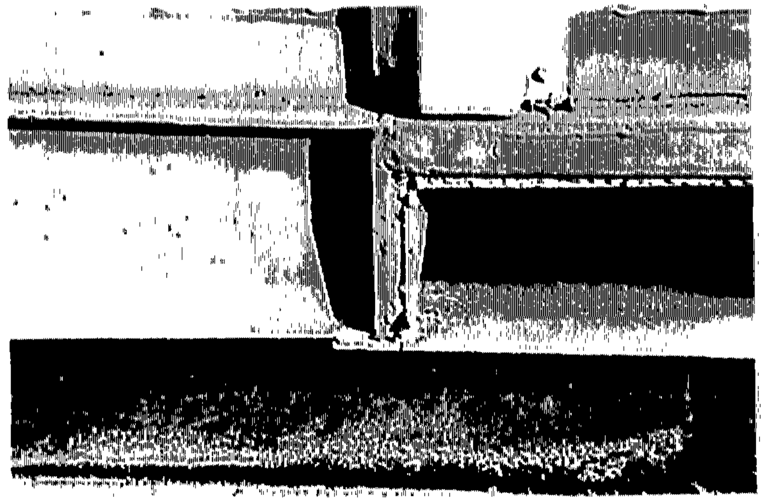


Figure 14 - Weld Crack

Figure 15 - Flooring Damage

After each drop the container was inspected in the following areas:

1. container doors

2. container flooring for integrity

3. floor cross member deformation

4. structural defects other than the above (i.e. broken welds, missing rivets, bent wall or roof members or panels)

5. load condition

6. dunnaging condition

7. pallet condition

Container failure is defined as:

1. Distortion and/or breakage of the container of a magnitude that prevents further handling

2. Distortion and/or damage to the container such as to prevent the door from being opened and/or unloading operations from being conducted

3. Crushing of the container shell into the storage area to the extent that cargo would be damaged

4. Damage to container floor such that contents could spill out

DATA ACQUISITION

1. Instrumented Data

Data was collected from accelerometers mounted externally (on two diagonally opposite corner post fittings) and internally (two on deadloads corresponding to the external ones and two mounted on palletized deadloads). Figures 16 and 17 depict the accelerometer locations for the half load and full load configurations, respectively. The abstract data sheet is included as Appendix A. (See "Analysis of Instrumented Data") The shock data was recorded as traces on light sensitive tapes.

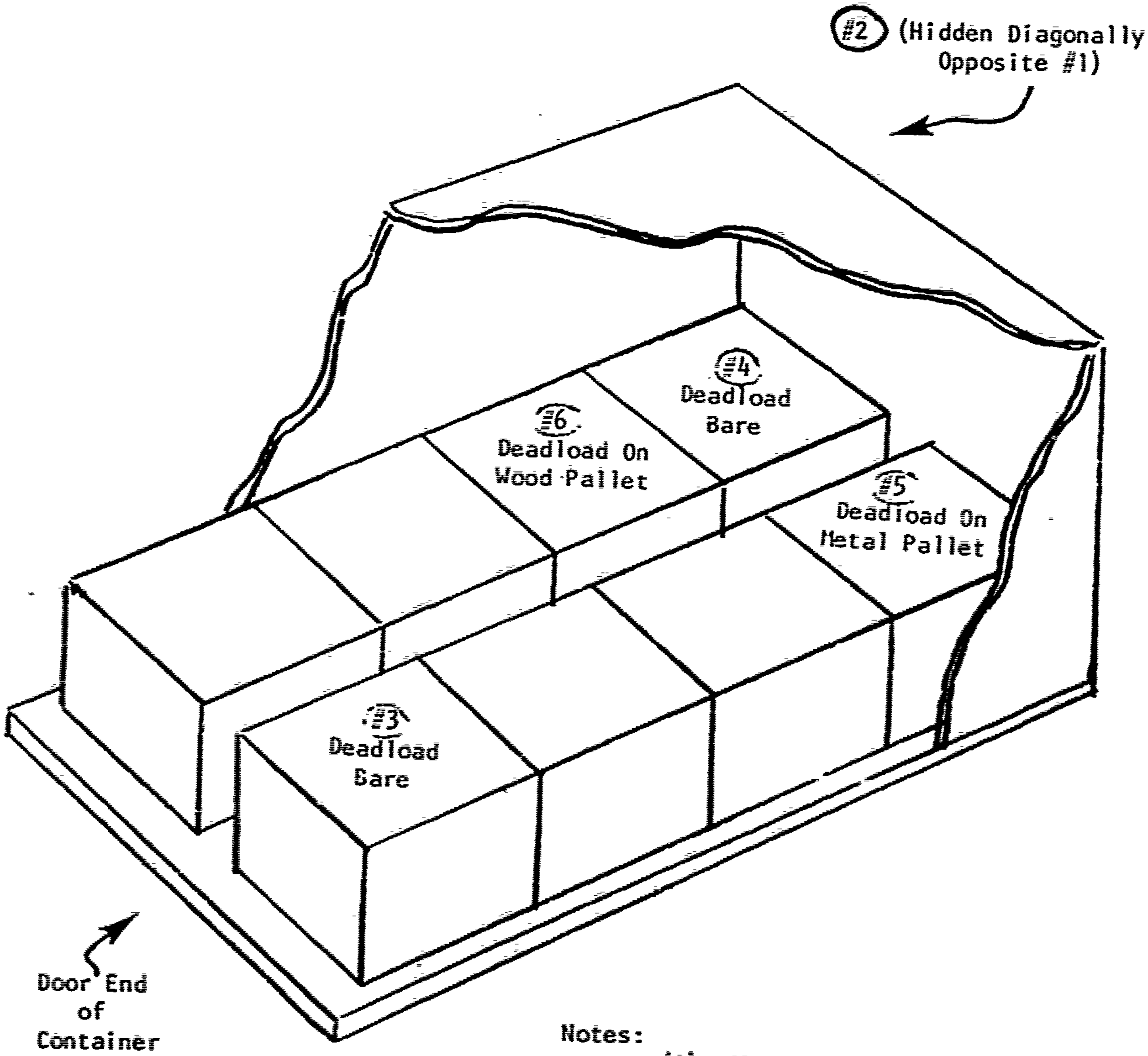
The following equipment was used:

Accelerometers:
- (2) ea. Statham A 5a - 100 - 350
- (2) ea. Statham A 5a - 200 - 350
- (2) ea. CEC 4 - 202 - 001

Shock Recorded Through:
- (6) ea. Honeywell Model 1885-SGC Strain Gage Control Modules
- (1) ea. Honeywell Model 1858 Visicorder

2. Visually Acquired Data

All containers were new prior to the test program. Therefore all damage or deterioration was attributable to the tests conducted. The hazards involved precluded making a detailed quantitative inspection of the underside of the container after each drop. Inspections of the container interior were also limited due to access when the containers were in a loaded configuration. Whenever possible, photographs and comprehensive inspection remarks by experienced personnel were utilized.



Notes:

(1) Sketch shows arrangement for 2,000 Pound Deadload Weight

(2) Numbers in circles identify accelerometer locations.

Figure 16 - Sketch of Accelerometer Locations
(Single Tier)

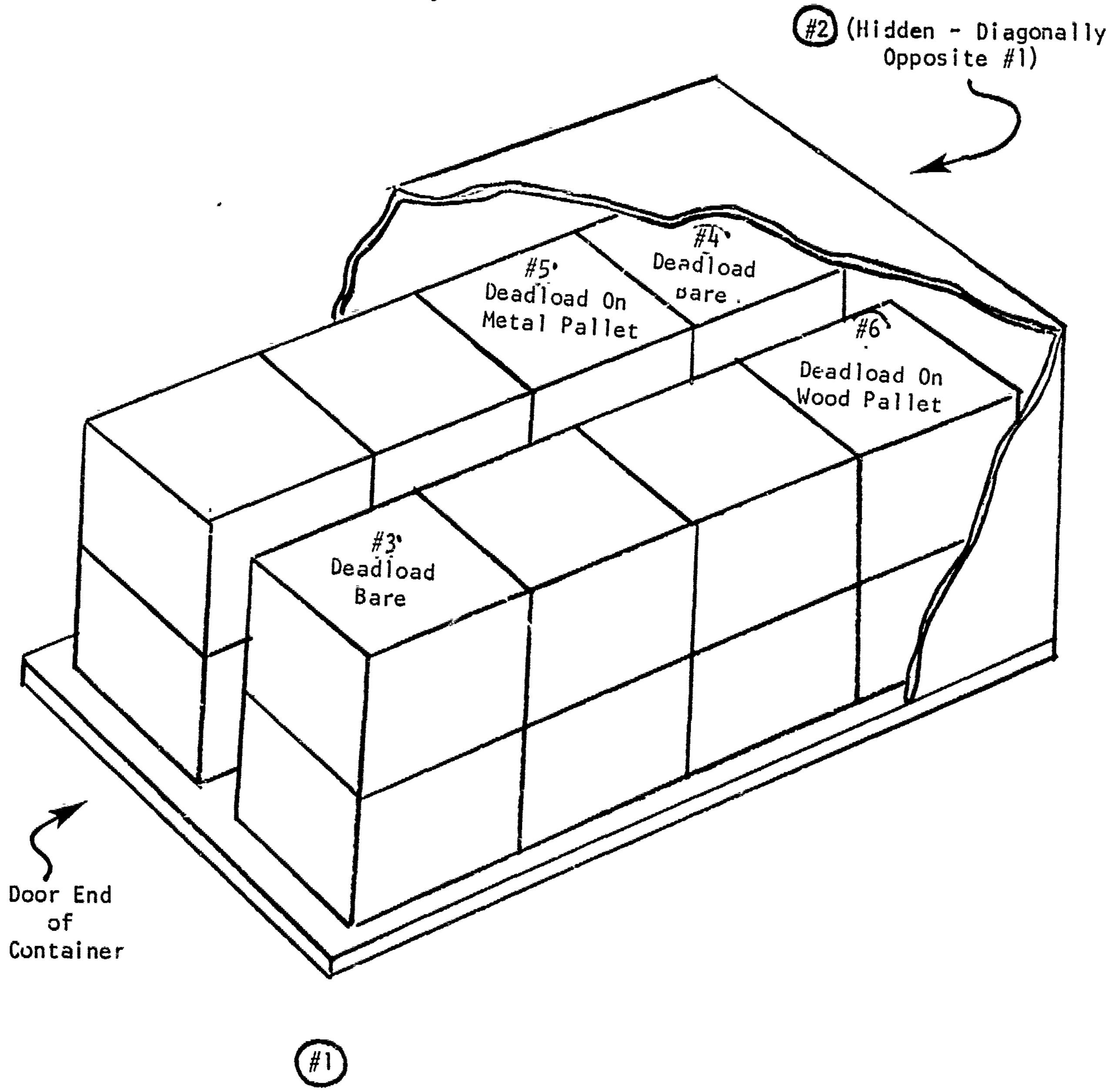


Figure 32 - Sketch of Accelerometer Locations
(Double Tier)

RESULTS OF TESTING

1. Analysis of Instrumented Data

Figures 18, 19, 20 and 21 are plots of peak shock levels measured at the containers lower corner post as a function of initial impact velocity of the container for the various impact configurations tested. Figure 22 is a composite which compares the upper limits for each of the foregoing conditions. The worst conditions occured during corner drops impacting against the bare surface as shown in Figure 22. When impacted against 9-pound density, 6-inch thick polyethylene foam, peak shock levels during the corner drops were reduced by more than half. In all cases bare flat drops resulted in shock levels which were lower than corner drops at equivalent impact velocities. Flat drops onto the cushioned surface produced the lowest "g" levels of all, but the upper limit curve for that configuration and that of the corner drop with cushions appear to coincide beyond impacts of 10 fps; but in light of the limited amount of data available for each of these test configurations, any attempts to explain this occurrence would be purely speculative.

There is no clear correlation between container gross weight and recorded shock levels (Figures 18 through 21).

Figures 23 through 26 plot peak shock levels for the deadloads as a function of container initial impact velocity for the four impact configurations. Each of the deadload conditions, whether bare (directly on the container floor) or palletized on either wood or metal pallets, is identified. Figure 27 compares the upper limit curves for the four drop configurations and shows that the corner drop on a bare surface produces the greatest shock levels to the contents. Corner drops on the foam cushioning result in less severe shock levels. Flat drops, both bare and cushioned, resulted in somewhat lower shocks.

The significance of Figure 27 is to demonstrate that the 9-pound density cushioning utilized during these tests does provide some degree of shock mitigation to containerized contents, at least for the corner drop situation. However, the data tends to indicate that for flat drops, cushioning had little influence on the amount of peak shock recorded.

Interestingly, Figures 23 through 26 demonstrate that gross container weight does have an effect on peak shock levels imparted to the deadloads. In all four configurations peak g's were significantly higher for the full load condition (45,000 pounds) than the half-load (25,000 pounds) condition. The explanation for this is unknown, but factors such as container floor frequency response and rigidity of the cushioning are considered to be influencing factors. Further discussion on this aspect of the program is presented in the Appendices.

Figures 28, 29, 30 and 31 compare the peak shock curves for the commodities to the peak shock levels recorded at the container corner fittings. For three of the configurations, flat drop on cushion, flat drop on bare surface and corner drop on bare surface, commodity shock levels are consistently lower than the shock pulses transmitted to the corner posts. This indicates that some attenuation takes place due to either container floor or pallet deflection and deformation. In the corner drop and cushion surface condition (Figure 29) the commodity g's exceeded the corner fitting g's beyond approximately 5 fps of initial impact. Again, the reason is not clear, but many factors can likely influence the situation. This is also discussed in Appendix B.

PEAK "G's" vs INITIAL IMPACT VELOCITY
FLAT DROP/CUSION SURFACE

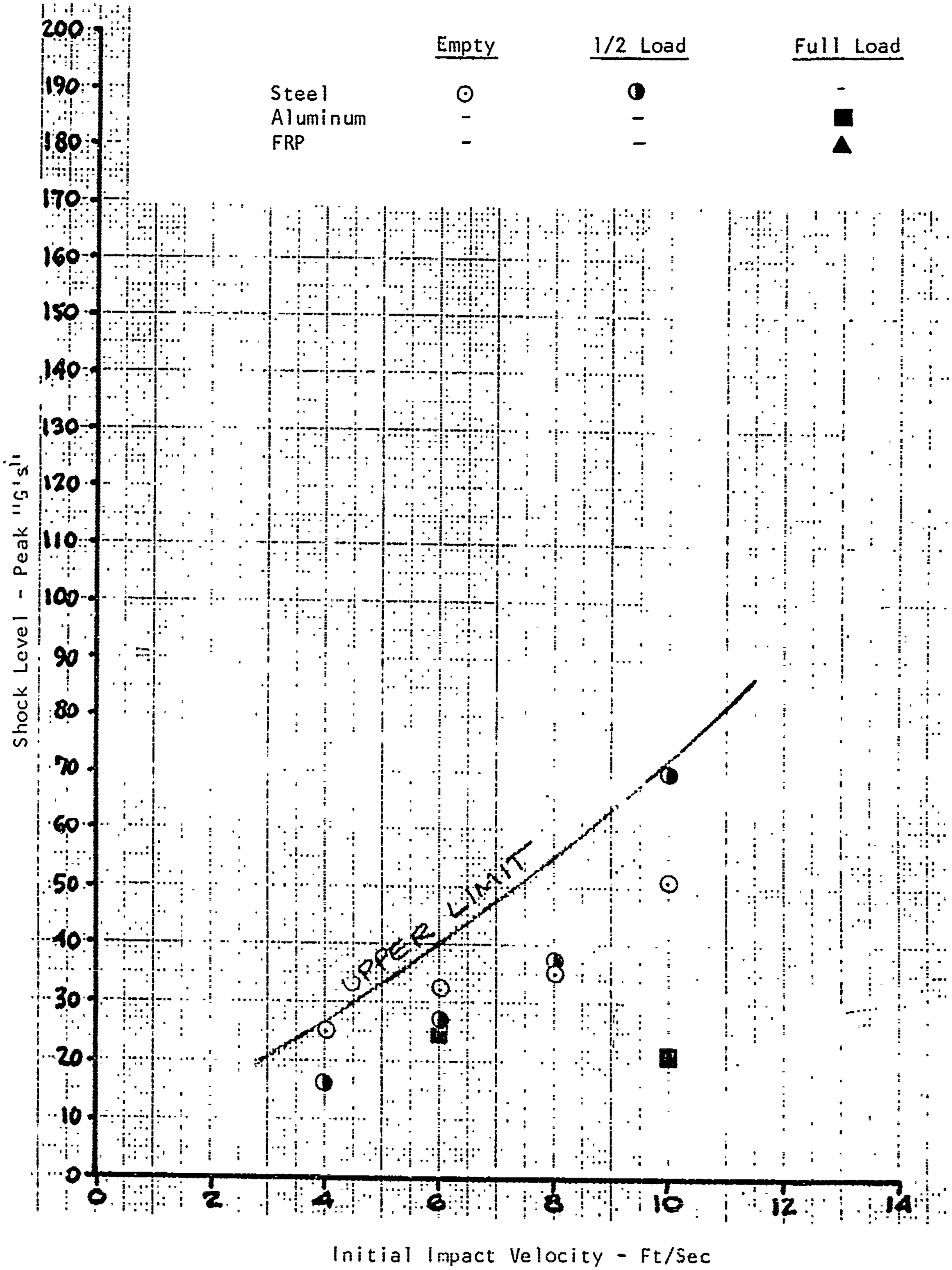


Figure 18

PEAK "G's" vs INITIAL IMPACT VELOCITY
CORNER DROP/CUSHION SURFACE

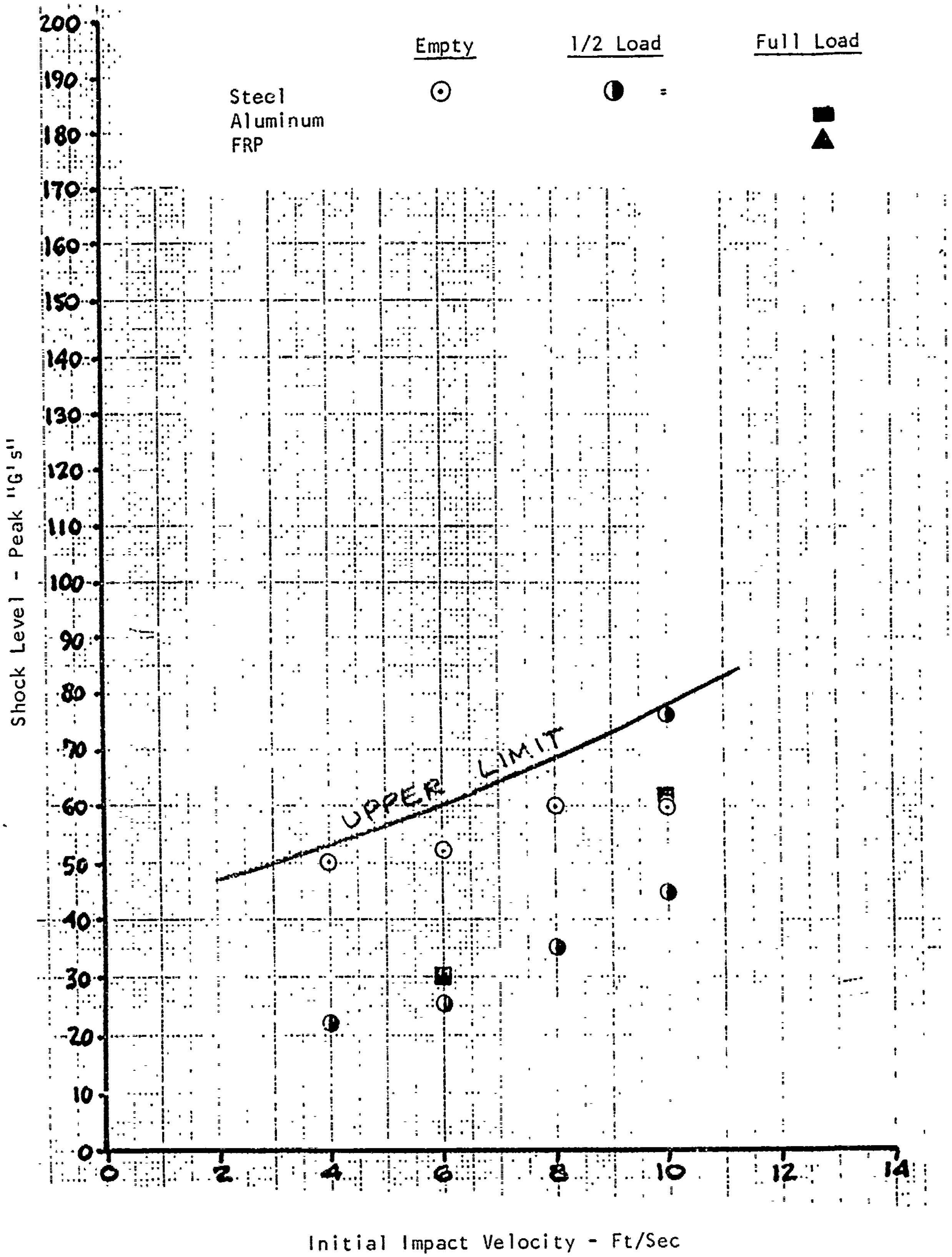


Figure 19

PEAK "G's" vs INITIAL IMPACT VELOCITY
FLAT DROP/BARE SURFACE

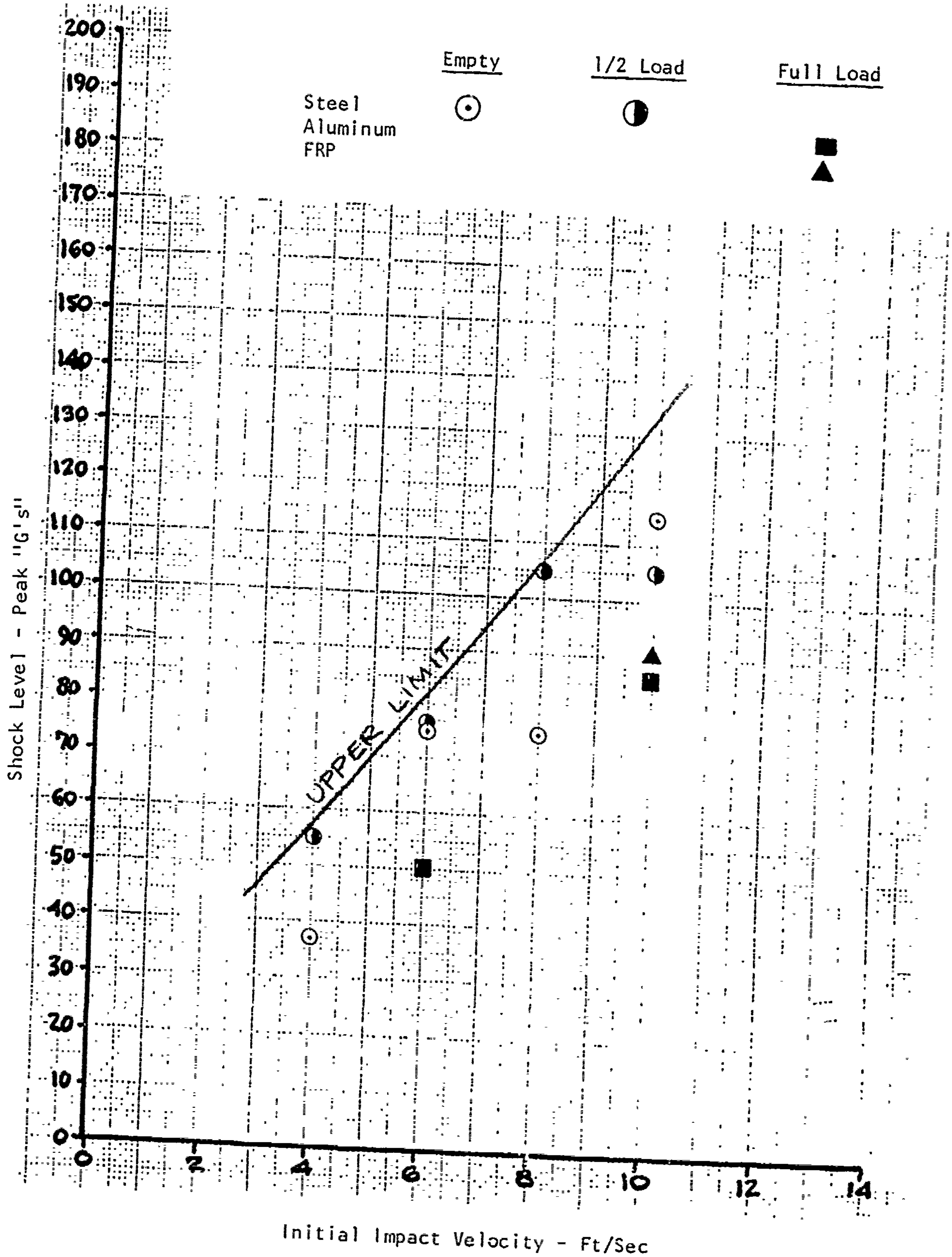


Figure 20

PEAK "G's" vs INITIAL IMPACT VELOCITY
CORNER DROP/BARE SURFACE

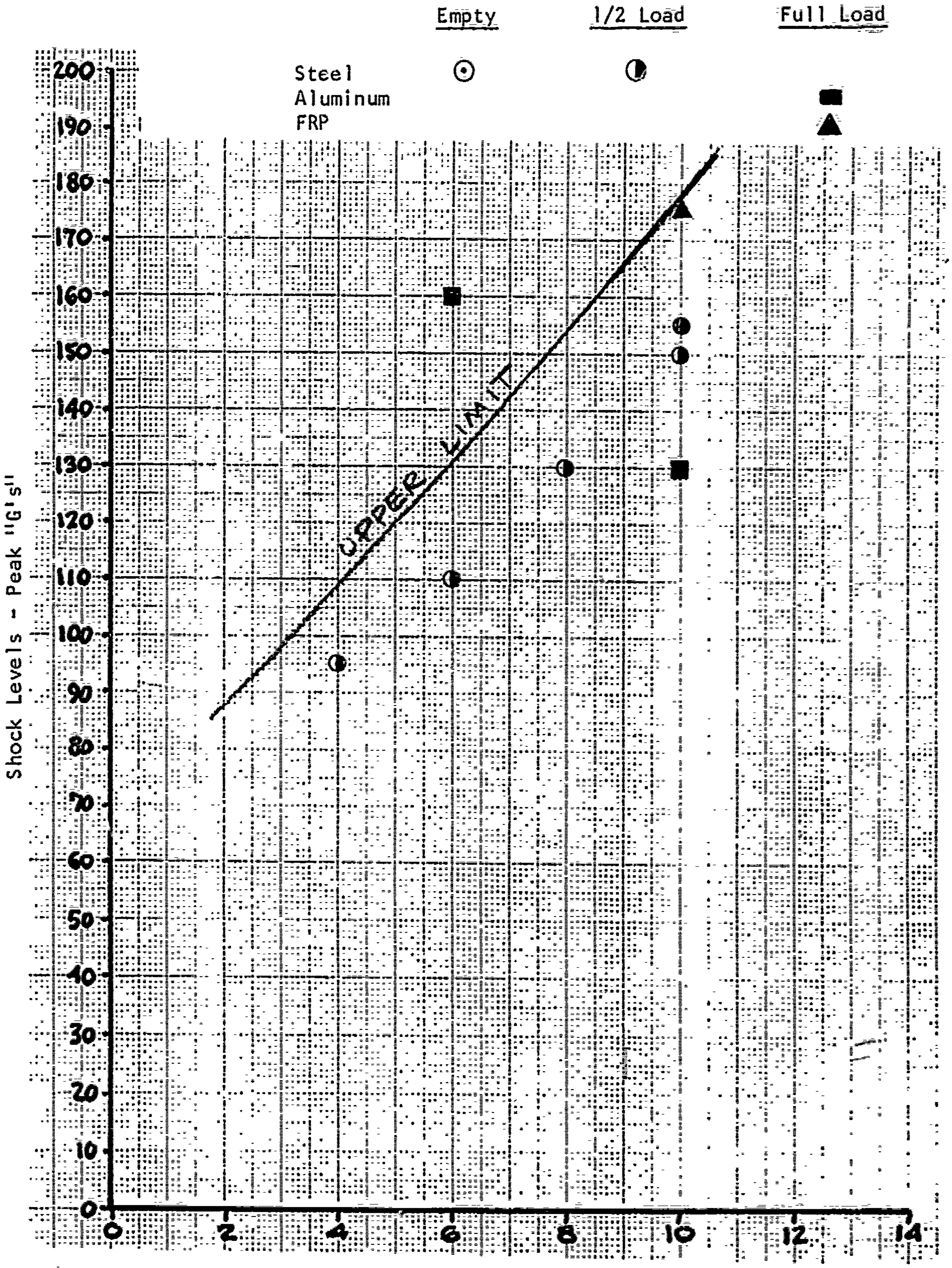


Figure 21

PEAK "G's" vs INITIAL IMPACT VELOCITY
at CONTAINER LOWER CORNER FITTING

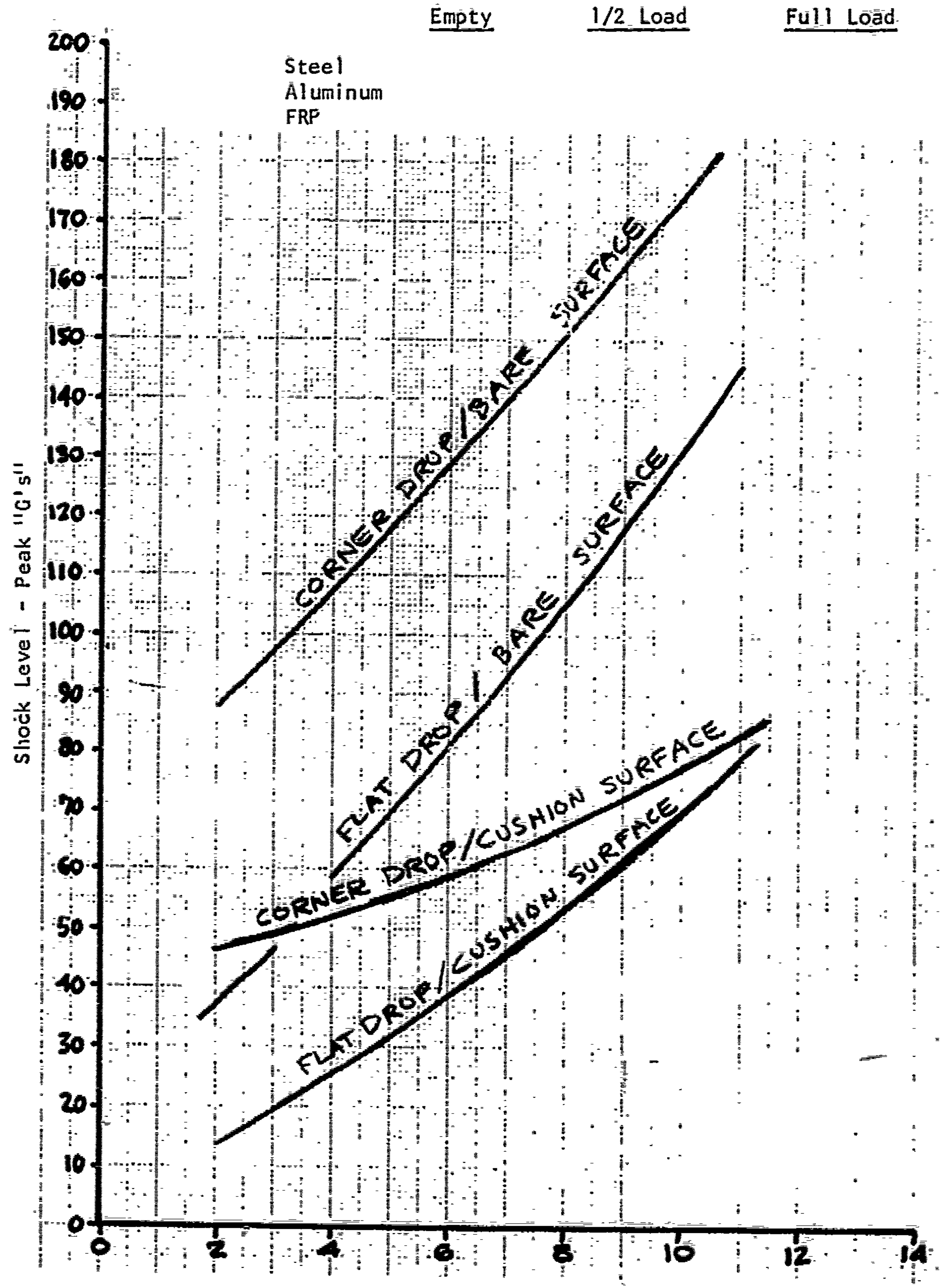


Figure 22

PEAK "G's" vs INITIAL IMPACT VELOCITY
FOR COMMODITIES
FLAT DROP/PADDED SURFACE

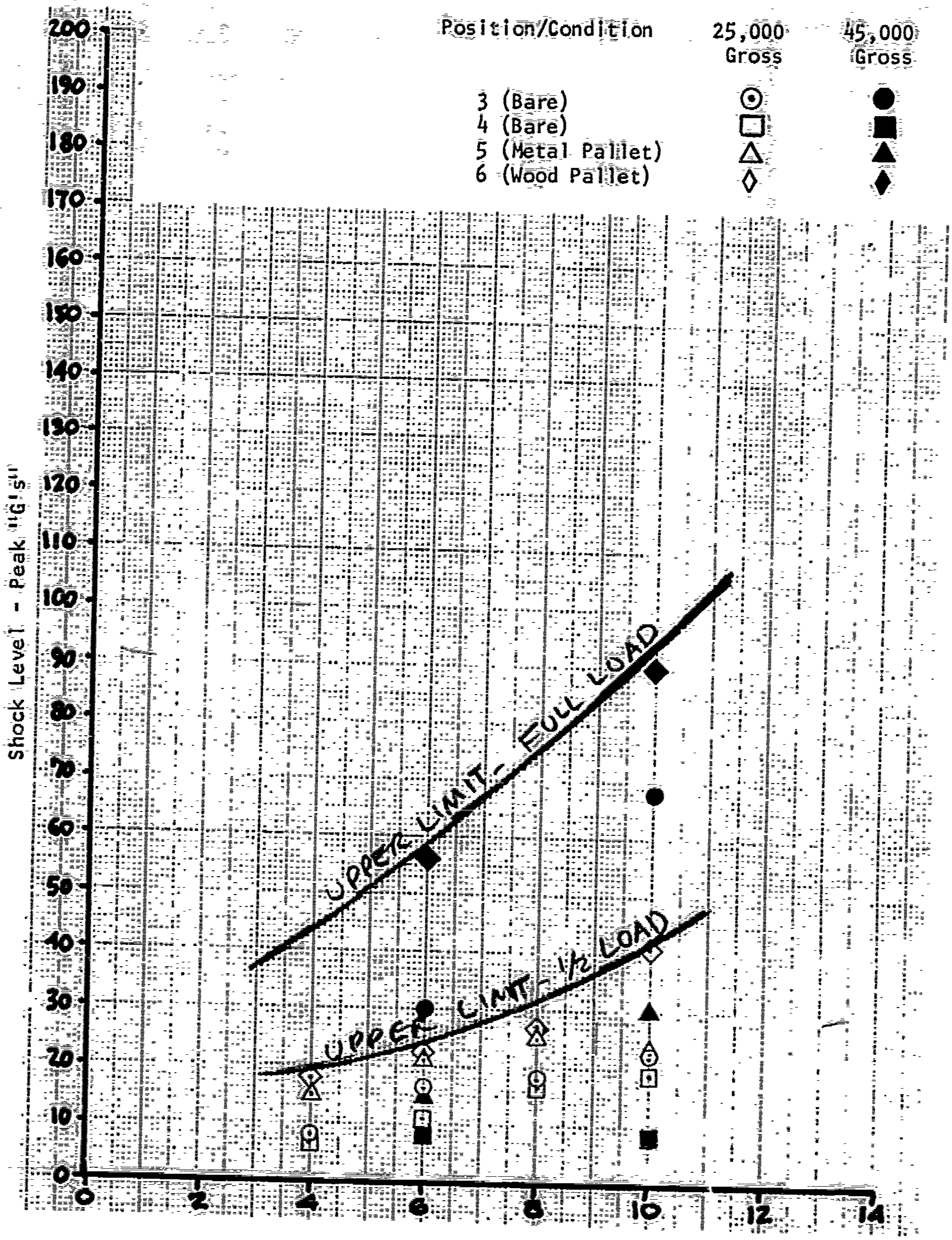


Figure 23

PEAK "G's" vs INITIAL IMPACT VELOCITY
FOR COMMODITIES
CORNER DROP/CUSHIONED SURFACE

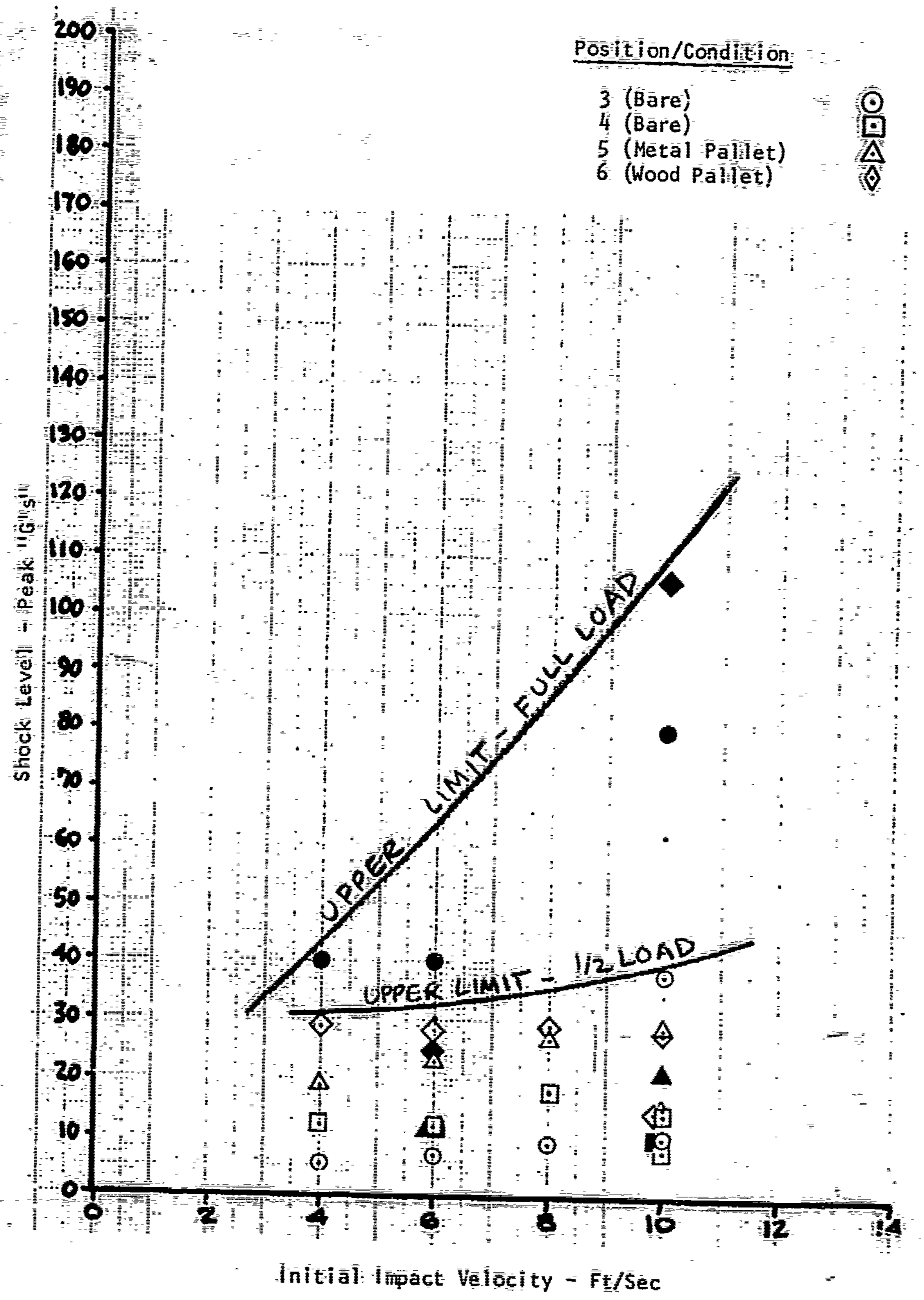


Figure 24

PEAK "G's" vs INITIAL IMPACT VELOCITY
FLAT DROP/BARE SURFACE

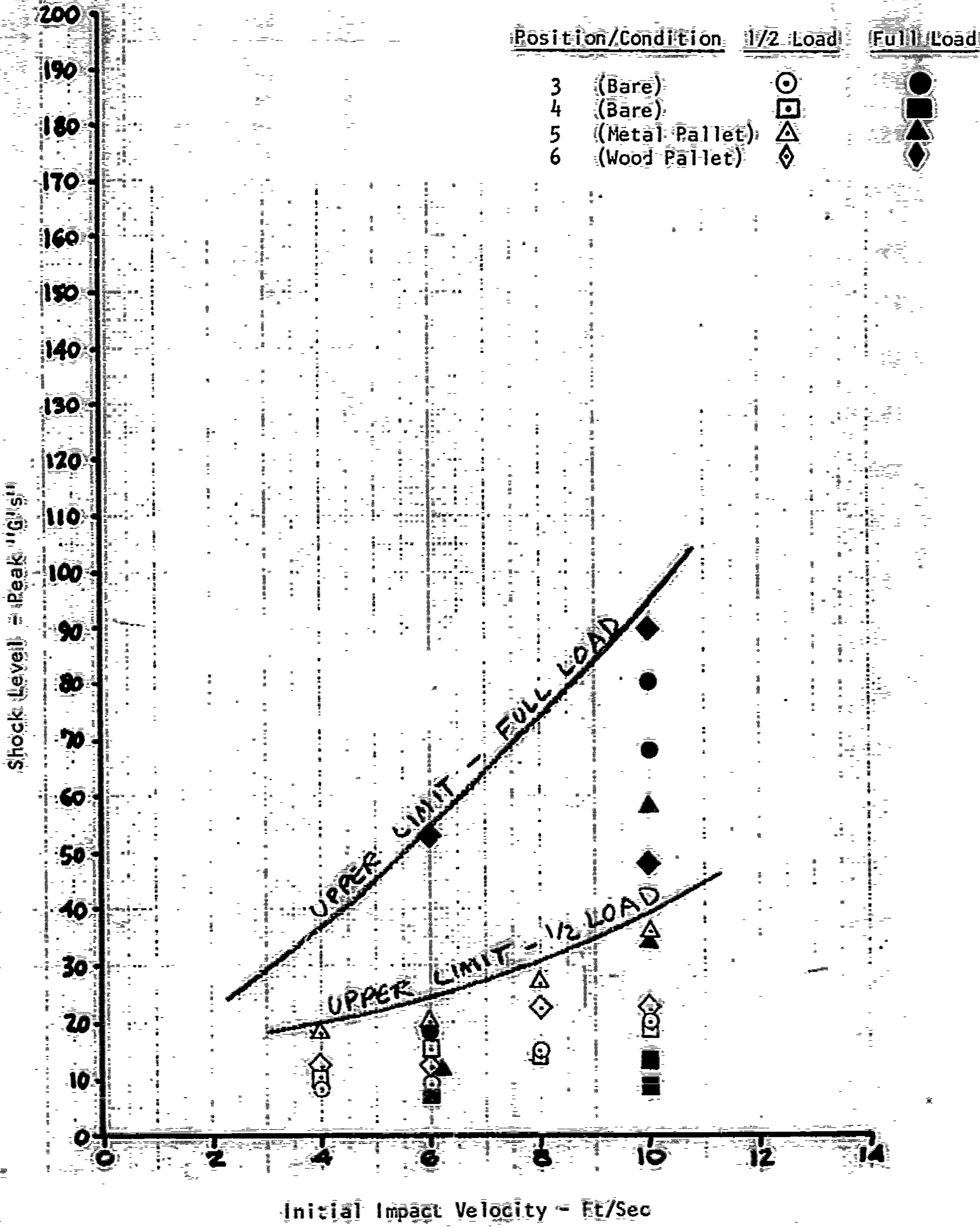


Figure 25

PEAK "G's" vs INITIAL IMPACT VELOCITY
FOR COMMODITIES
CORNER DROP/BARE SURFACE

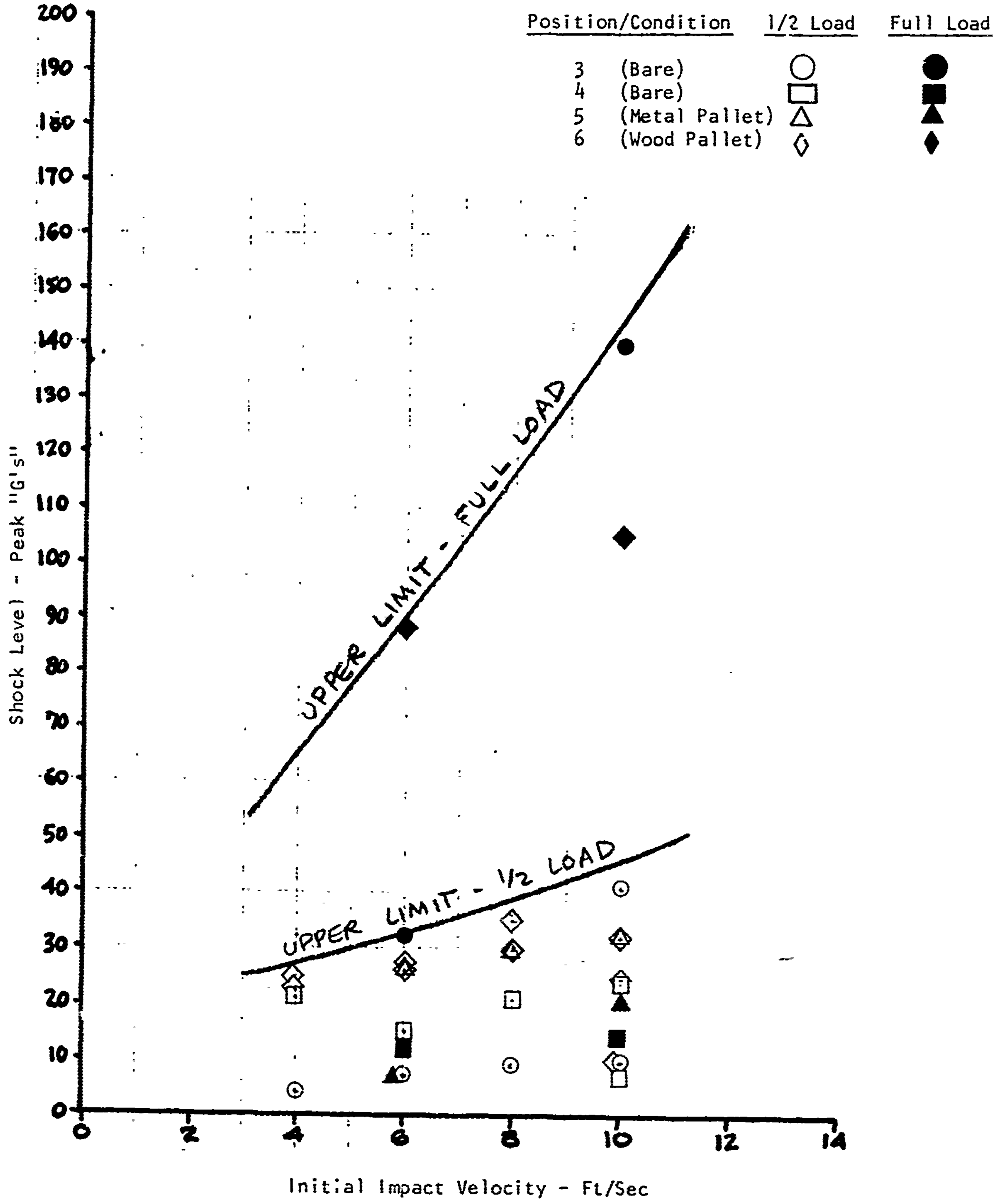


Figure 26

PEAK "G's" vs INITIAL IMPACT VELOCITY
FOR COMMODITIES

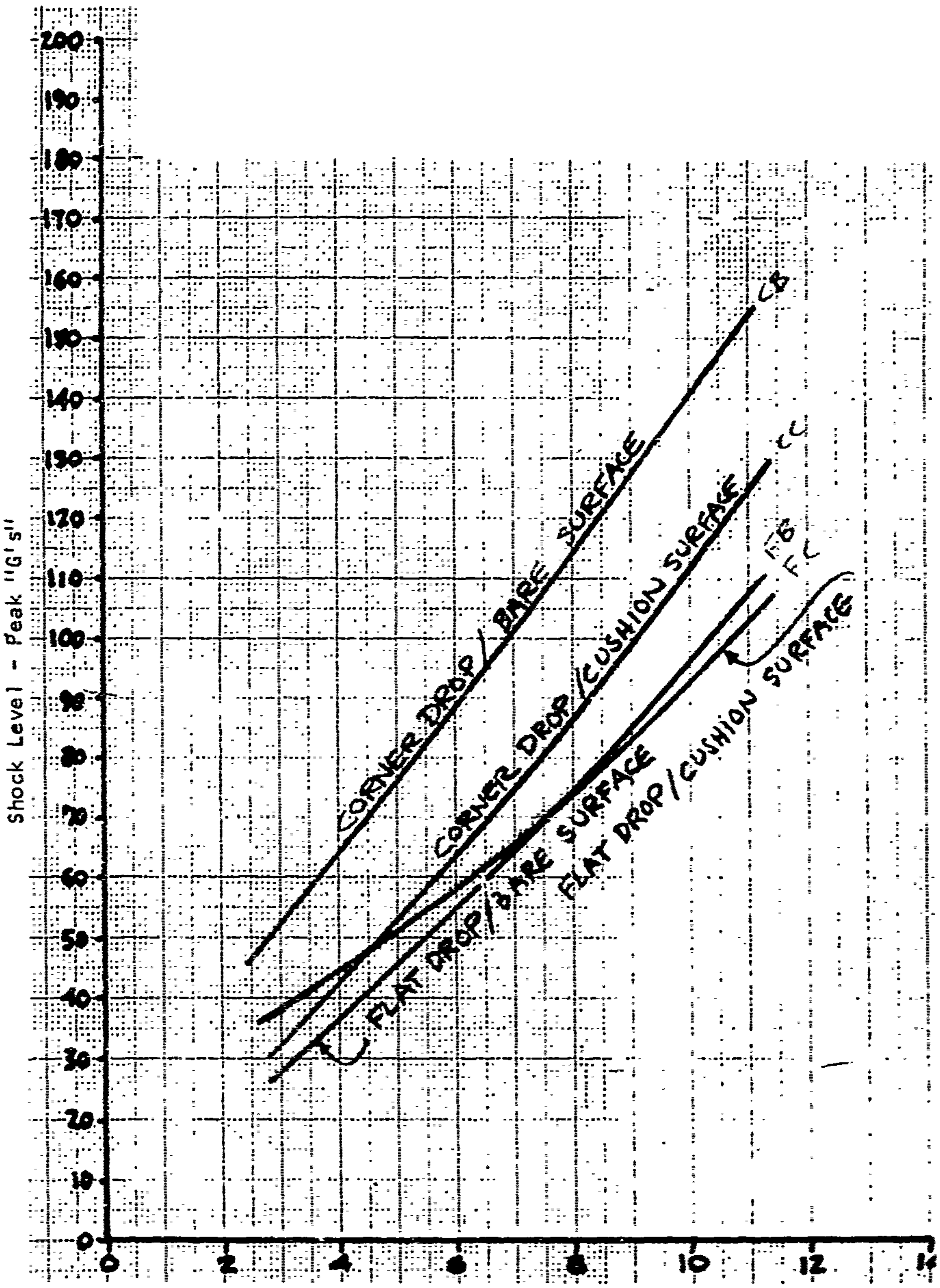


Figure 27

PEAK "G's" vs INITIAL IMPACT VELOCITY
FLAT DROP/CUSHION SURFACE

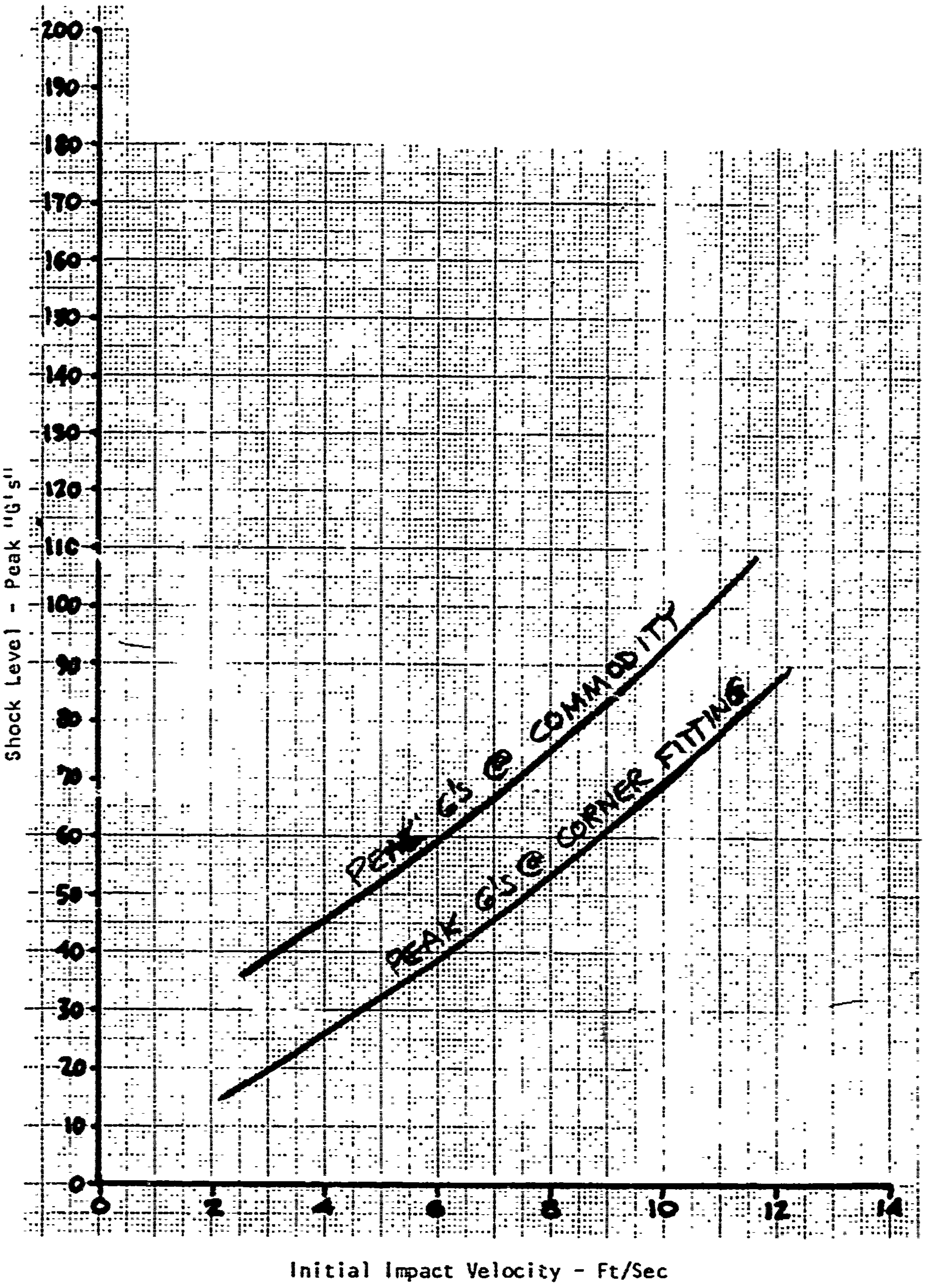


Figure 28

PEAK "G's" vs INITIAL IMPACT VELOCITY
CORNER DROP/CUSHION SURFACE

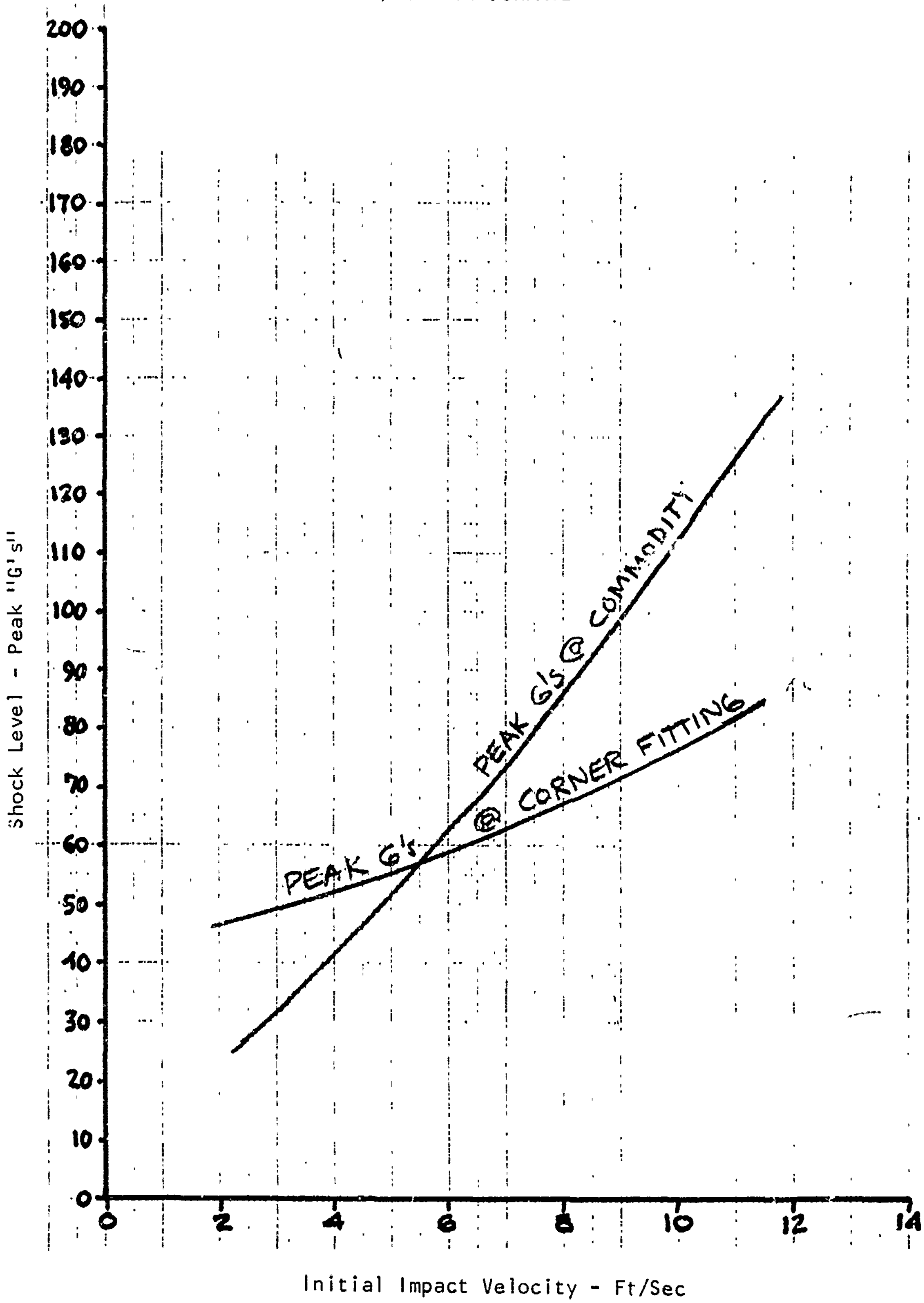


Figure 29

PEAK "G's" vs INITIAL IMPACT VELOCITY
FLAT DROP/BARE SURFACE

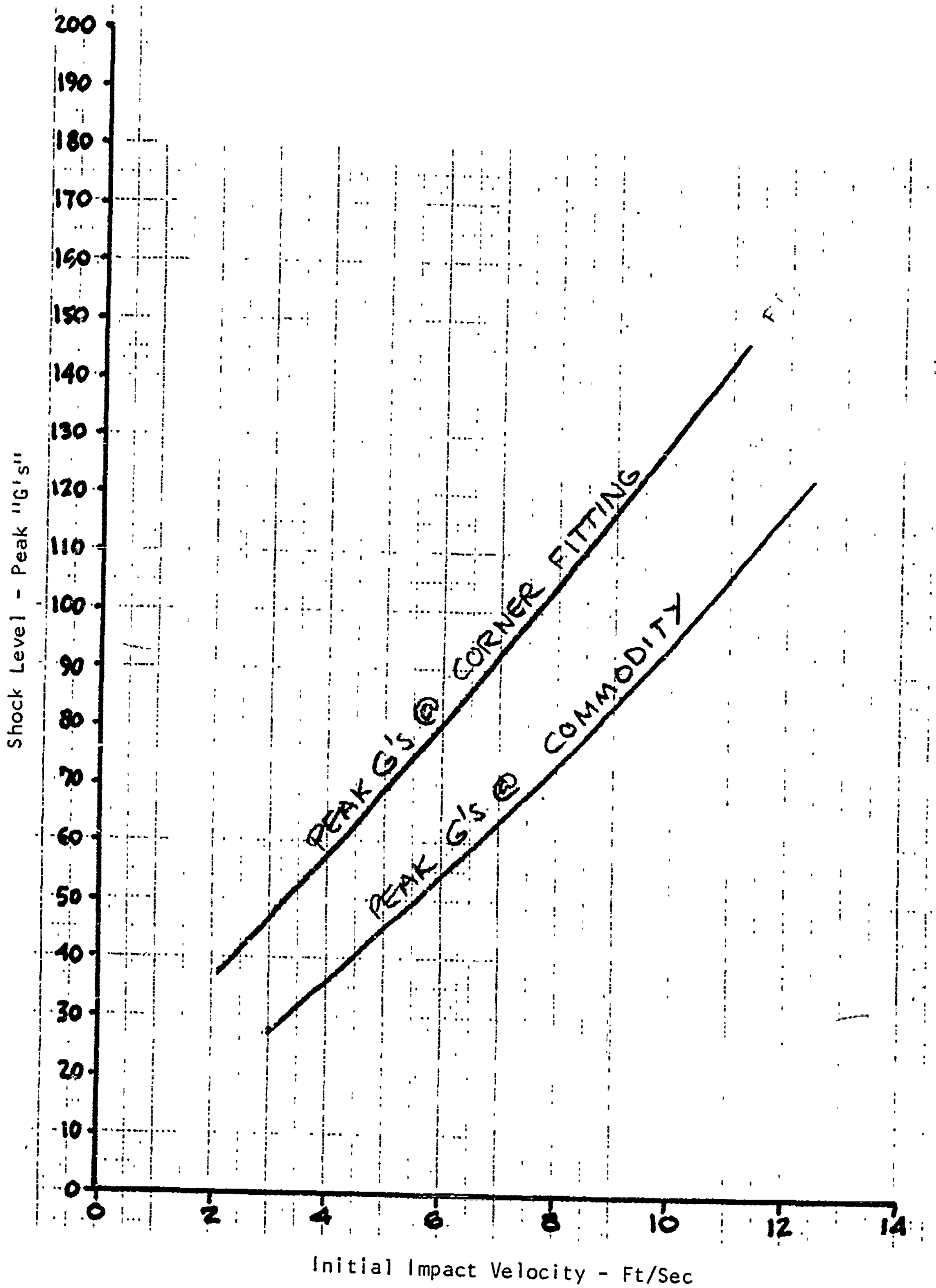


Figure 30

PEAK "G's" vs INITIAL IMPACT VELOCITY
CORNER DROP/BARE SURFACE

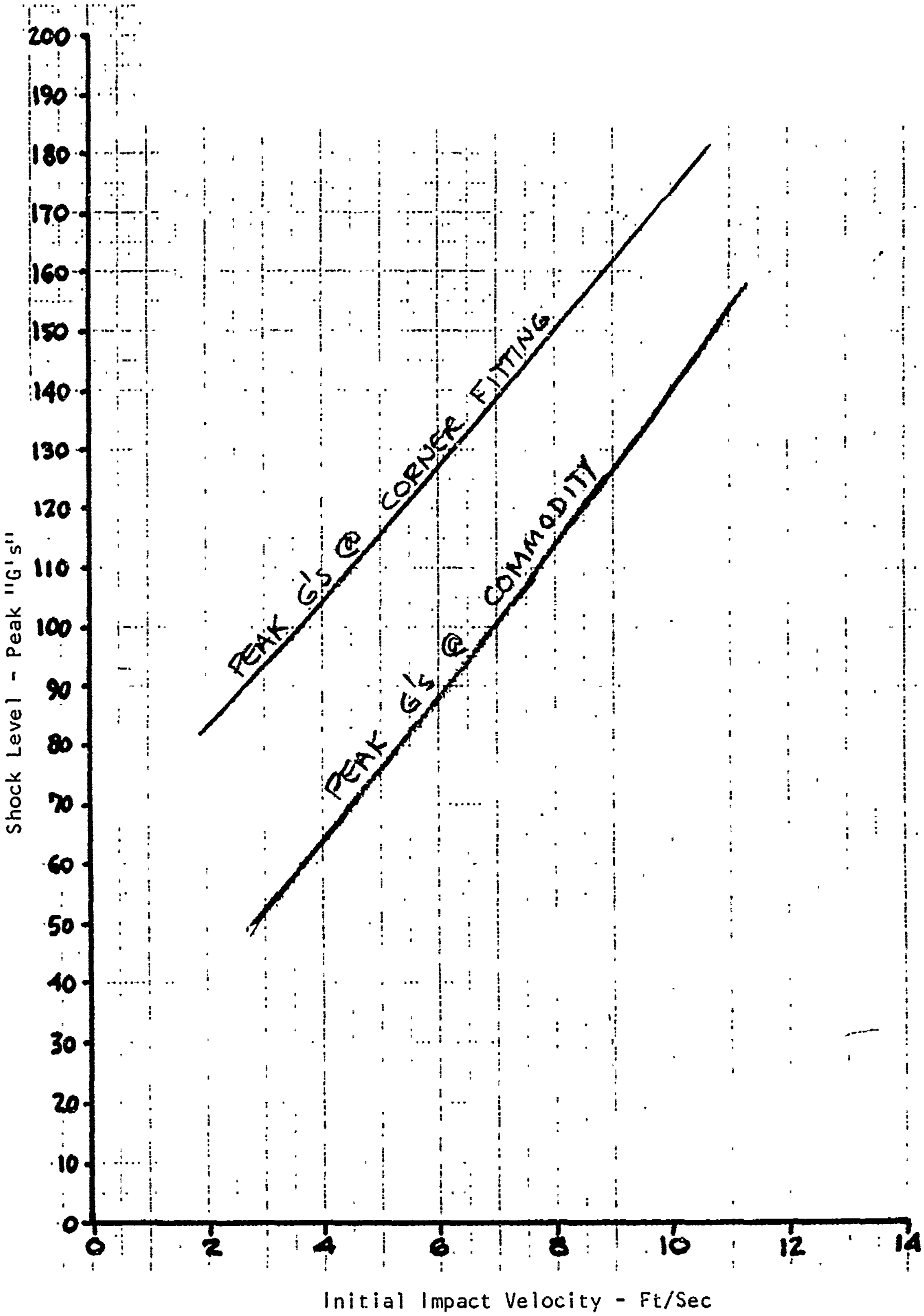


Figure 31

2. Container Endurance

Assessing container endurance was not absolutely accomplished during this test program. The number of variables involved, including load condition, impact velocity, drop attitude and surface condition, would have required a container to be dropped repetitively for each specific set of conditions until a failure, as described earlier, occurred. This approach would have required up to 48 separate containers of each type. Since these tests used three container types, a total of 144 containers would have been necessary to empirically determine the endurance limit for the containers. Since the tests were limited to one of each type of container, a less rigorous means was used to establish some guidelines relevant to container endurance.

First, it is noted that the curves of Figure 22 show that severity of container impact, or shock level achieved, depends upon container drop attitude and impact surface condition. According to the data the least severe is the flat drop on the padded surface; next is the corner drop on the padded surface; next the flat drop on the bare surface and the most severe, the corner drop on the bare surface. This relative severity of impact is depicted in Figure 32.

From this information it can be concluded that if a container withstood a number of impacts at increasingly severe conditions, it could have withstood at least that number of impacts at the least severe condition. To illustrate this, consider the impacts conducted with the all-steel container at 10 fps. A total of 10 such impacts were done at that velocity at no-load, half-load, corner drop, flat drop bare and padded surface conditions. Table II depicts all of the impacts conducted with the three types of containers tested. Although only one 10 fps event was conducted at the least severe condition (empty container, flat drop cushioned surface), nine other events were conducted at more severe conditions. Therefore, a reasonable conclusion is that the container would have survived at least 10 impacts at the least severe condition. This rationale is applied to all the 10 fps events. For what is considered to be the worst case situation (10 fps half-load, bare, corner drop), only one event was conducted. Therefore, it is known that the container can survive at least one such event of that type. However, considering that the container specimen successfully withstood numerous impacts (33 prior events) prior to the worst case hit, it is probable that a new container would withstand several impacts at the worst case condition if such a condition were the only impacts conducted.

A summary of demonstrated minimum endurance of 6 fps and 10 fps impacts for the three types of containers evaluated is shown in Tables III and IV, respectively. Minimum endurance at impact velocities other than 6 fps and 10 fps can be obtained using the same methodology as described above in conjunction with the information contained in Table II.

CORNER DROP
CUSHION SURFACE

CORNER DROP
BARE SURFACE

LOW	←	SEVERITY	→	HIGH

FLAT DROP
CUSHION SURFACE

FLAT DROP
BARE SURFACE

Figure 32 - Relative Severity of Impact to Containers as a Function of drop attitude and impact surface.

CONTAINER	APPROX. GROSS WEIGHT	IMPACT VELOCITY	DROP CONFIGURATION				NUMBER OF HITS
			FLAT/CUSHION	CORNER/CUSHION	FLAT/BARE	CORNER/BARE	
Steel (Strick Corp)	5,000 pounds (Empty Container)	4	1	1	1	1	4
		6	1	1	1	1	4
		8	1	1	1	1	4
		10	1	1	1	1	4
		TOTAL	4	4	4	4	16
	25,000 pounds (Half Load)	4	1	1	1	1	4
		6	1	1	1	1	4
		8	1	1	1	1	4
		10	1	2	1	2	6
		TOTAL	4	5	4	5	18
Aluminum Panel (Theurer Corp)	45,000 pounds (Full Load)	4	0	0	0	0	0
		6	1	1	1	1	4
		8	0	0	0	0	0
		10	1	1	1	1	4
		TOTAL	2	2	2	2	8
Fiberglass Reinforced Plywood (Theurer Corp)	45,000 pounds (Full Load)	4	0	0	0	0	0
		6	0	0	0	0	0
		8	0	0	0	0	0
		10	0	0	1	1	2
		TOTAL	0	0	1	1	2

TABLE II - Summary of Tests Conducted at Each Configuration

CONTAINER	APPROX. GROSS WEIGHT	MINIMUM NUMBER OF IMPACTS @ 6 FT/SEC DROP CONFIGURATION			
		FLAT/CUSHION	CORNER/CUSHION	FLAT/BARE	CORNER/BARE
Steel (Strick Corp)	5,000 pounds (Empty Container)	26	20	13	7
	25,000 pounds (Half Load)	14	11	7	4
Aluminum Panel (Theurer Corp)	45,000 pounds (Full Load)	8	6	4	2
Fiberglass Reinforced Plywood (Theurer Corp)	45,000 pounds (Full Load)	2	2	2	1

TABLE III - Minimum Demonstrated Container Endurance at 6 Ft/Sec Impact

CONTAINER	APPROX. GROSS WEIGHT	MINIMUM NUMBER OF IMPACTS @ 6 FT/SEC DROP CONFIGURATION			
		FLAT/CUSHION	CORNER/CUSHION	FLAT/BARE	CORNER/BARE
Steel (Strick Corp)	5,000 pounds (Empty Container)	10	8	5	3
	25,000 pounds (Half Load)	6	5	3	2
Aluminum Panel (Theurer Corp)	45,000 pounds (Full Load)	4	3	2	1
Fiberglass Reinforced Plywood (Theurer Corp)	45,000 pounds (Full Load)	2	2	2	1

TABLE IV - Minimum Demonstrated Container Endurance at 10 Ft/Sec Impact

CONCLUSIONS

Using data acquired visually and also by reviewing the accelerometers readings, the following conclusions are reached:

1. By the criteria established from the definition of container failure, none of the containers failed. Accordingly, this proves commercial intermodal containers can withstand impacts up to 10 fps fully loaded.

2. Container life is dependent on cumulative effect of impacts.

3. The container floor deforms and/or fractures to mitigate the shock of an impact.

4. Foam padding greatly reduces the impact levels imparted to the container; however, a foam with a density of 4 pcf is predicted to afford protection to the container and its contents.

5. Lack of shock mitigation by the pallets was probably due to resonant frequency response.

6. Peak g's increased with velocity.

7. Corner drops generally result in higher peak g readings

RECOMMENDATIONS

The following recommendations are offered:

1. That passive shock mitigation be utilized, either exclusively or in conjunction with motion compensating cranes, to implement intermodal container transfer from containership to barge or lighter in up to Sea State 3 conditions.

2. That further evaluations be conducted utilizing 4 pcf foam padding to confirm the additional shock reduction to container contents predicted by mathematical analysis.

APPENDIX A

COTS CONTAINER DROP TESTS
ABSTRACT DATA SHEET

DROP NO.	NOMINAL VELOCITY at Impact fps	PEAK g's ACCELEROMETER LOCATION 1	2	3	4	5	6
Container, All Steel (Mfg by Strick); Load, None; Attitude; Flat; Surface; Padded							
1	4	13	25				
2	6	22	32				
3	8	32	35				
4	10	51	40				
Container, All Steel; Load, None; Attitude, Corner; Surface, Padded							
5	4	8	50				
6	6	10	52				
7	8	13	60				
8	10	16	60				
Container, All Steel; Load, None; Attitude; Level; Surface, Bare							
9	4	37	18				
10	6	75	45				
11	8	75	65				
12	10	115	74				
Container, All Steel; Load, None; Attitude; Corner; Surface, Bare							
13	4	23	Inoperative				
14	6	65	"				
15	8	68	"				
16	10	100	"				
Container, All Steel; Load, 20,000#; Attitude, Flat; Surface, Padded							
17	4	16	10	8	7	15	18
18	6	20	27	16	[illegible]	21	22
19	8	37	20	18	17	25	27
20	10	70	42	22	19	23	41
Container, All Steel; Load 20,000#; Attitude, Corner; Surface, Padded							
21	4	20	22	5	12	19	29
22	6	20	25	7	12	23	28
23	8	22	35	9	18	27	29
24	10	20	40	10	14	29	28
25	10	76	45	38	8	15	11

DROP NO.	NOMINAL VELOCITY at Impact fps	PEAK g's ACCELEROMETER LOCATION 1	2	3	4	5	6
Container, All Steel; Load, 20,000 #; Attitude, Flat; Surface, Bare							
26	4	55	35	8	10	18	12
27	6	76	48	9	15	20	12
28	8	105	102	15	14	27	22
29	10	110	100	20	19	36	22
Container, All Steel; Load, 20,000#; Attitude, Corner; Surface, Bare							
30	4	45	95	4	21	22	24
31	6	60	110	7	15	26	28
32	8	85	130	9	21	30	35
33	10	115	155	10	24	32	32
34	10	150	120	41	7	25	10
Container, Aluminum Panel (Mfg by Theurer); Load, 40,000#; Attitude, Flat, Surface Padded							
35	6	25	18	30	8	15	56
36	10	21	18	68	8	30	90
Container, Aluminum Panel; Load, 40,000#; Attitude, Corner; Surface, Padded							
37	6	11	30	40	12	11	24
38	10	15	62	80	10	21	106
Container, Aluminum Panel; Load, 40,000#; Attitude, Flat; Surface, Bare							
39	6	50	30	18	7	12	53
40	10	86	80	68	13	35	90
Container, Aluminum Panel; Load, 40,000#; Attitude, Corner; Surface, Bare							
41	6	50	160	32	12	7	88
42	10	100	130	140	14	20	105
Container, FRP (Mfg by Theurer); Load Full; Attitude, Corner; Surface, Bare							
43	10	100	175	20	12	12	110
Container, FRP; Load, Full; Attitude, Flat; Surface, Bare							
44	10	85	90	80	8	58	48

NOTE: Accelerometer Location: #1 and 2 were external and at diagonal corner fittings throughout; #1 was at the door end and was the initially impacted corner in corner drops except for drops 25 and 34. For these two drops, #2 accelerometer received the initial impact. #3 and #4 were located on test load modules inside the container corresponding to #'s 1 and 2; #5 and #6 were on palletized test modules, throughout 20,000# drops. These locations were changed for 40,000# drops. #4 and #5 were at the door end, and #3 and #6 were at the closed end. All four were placed atop the upper tier.

APPENDIX B

ENCLOSURE (2)

3ND-NADK-8600/1

TEL. 462-9500

IN REPLY REFER TO NO

U. S. NAVAL AMMUNITION DEPOT EARLE

COLTS NECK, NEW JERSEY 07722

WH-8025-SRP:el
Ser. 1146-77
29 August 1977

From: Commanding Officer, Naval Weapons Station Earle
Colts Neck, NJ 07722

To: Commanding Officer, Naval Coastal Systems Laboratory
Acoustic Analysis Group (Code 772) Mr. P. Sextant
Panama City, FL 32401

Subj: COTS Container Impact Velocity Analysis

Ref: (a) Telecon between P. Sextant(NCSL) and S. Petoia (NWHC)
(b) NWHC ltr. WH-8025-FC:pr Ser. 1647-76 of 22 December 1976

Encl: (1) One copy of subject analysis

1. As discussed during reference (a), the mathematical derivations of container impact velocities utilized in conjunction with container drop test data reported upon in reference (b) are forwarded herein as enclosure (1). This information will also be included in the final report covering drop tests conducted by this activity to determine commercial container survivability when subjected to impacts resulting from transfer between container ship and lighter in a Container Offshore Transfer System (COTS) environment. The report will be completed by the end of the fiscal year.

2. If any questions concerning enclosure (1), please contact Mr. F. Ciccolella, Code 8025, Autovon 449-7675.

J E Kelly
J. E. KELLY
By direction

ANALYTICAL CO'PARISON OF VELOCITIES AT IMPACT IN A FREE FALL VERSUS TETHERED FALL

To determine the difference between a free fall impact of a cargo container inclined at an angle and a velocity controlled descent impact of the same container with the deck inclined at the same angle, impact velocity equations were derived and are attached as an appendix. In order to evaluate the free fall equation, it was required to determine the moments of inertia and radii of gyration of the container with various loads. The moment of inertia equation of the container is derived and evaluated for the various load configura' ons in the appendix.

Figure 1 presents a comparison between the two impact methods described by equations (4) and (11) for a container of dimensions 8' X 8' X 20' loaded to capacity (40,000 lbs and 4000 lb container) and impacting at both 4^{O} and 10^{O} attitudes. In this example, the load is 8' high, that is, it fills the container space. This figure is a plot of the most severse base velocity (at corner diagonally opposite impact corner) versus the initial impact velocity. Note that the initial impact velocity is the controlled decent velocit· Several observations can be made from Figure 1.

1. The controlled descent method is never more severe than the free fall case.

2. The controlled descent method approaches and becomes equal to the free fall method as initial impact velocity increases.

3. Larger impact angles result in greater differences between the two methods and equivalence is achieved at higher initial impact velocities.

4. Sensitivity to inclination angle decreases as initial impact

Enclosure (1)

velocity increases.

5. The greatest difference between the controlled descent method and the free fall method for the configuration analyzed above 20 fps initial impact velocity is no greater than 10%.

Figure 2 presents a family of error curves which graphically demonstrate the difference between the two methods (for the same configuration) in terms of the percentage increase in velocity resulting from simulating a controlled descent impact with a free fall impact having the same impact angle and initial impact velocity. Results are shown for 2°, 4°, 7° and 10° impact angles. Note that observation 5 above is clearly demonstrated by Figure 2.

Figure 3 was generated to demonstrate the effect of mass properties on the velocity calculations. The load configurations selected were 1/2 load, 8' high (low density) and full load, 2' high (high density). These configurations result in the greatest range of radius of gyration and cg height which consequently yield the greatest range of velocity calculations for given impact angles and initial impact velocity. The impact angle of Figure 3 is 7°. The significant observations of this figure are discussed below:

1. The controlled descent impact is not a function of the mass properties of the container.

2. The difference between high and low density load velocities due to free fall increases as the initial impact velocity increases, but the percent difference remains the same (approximately 14% based upon the low density velocity).

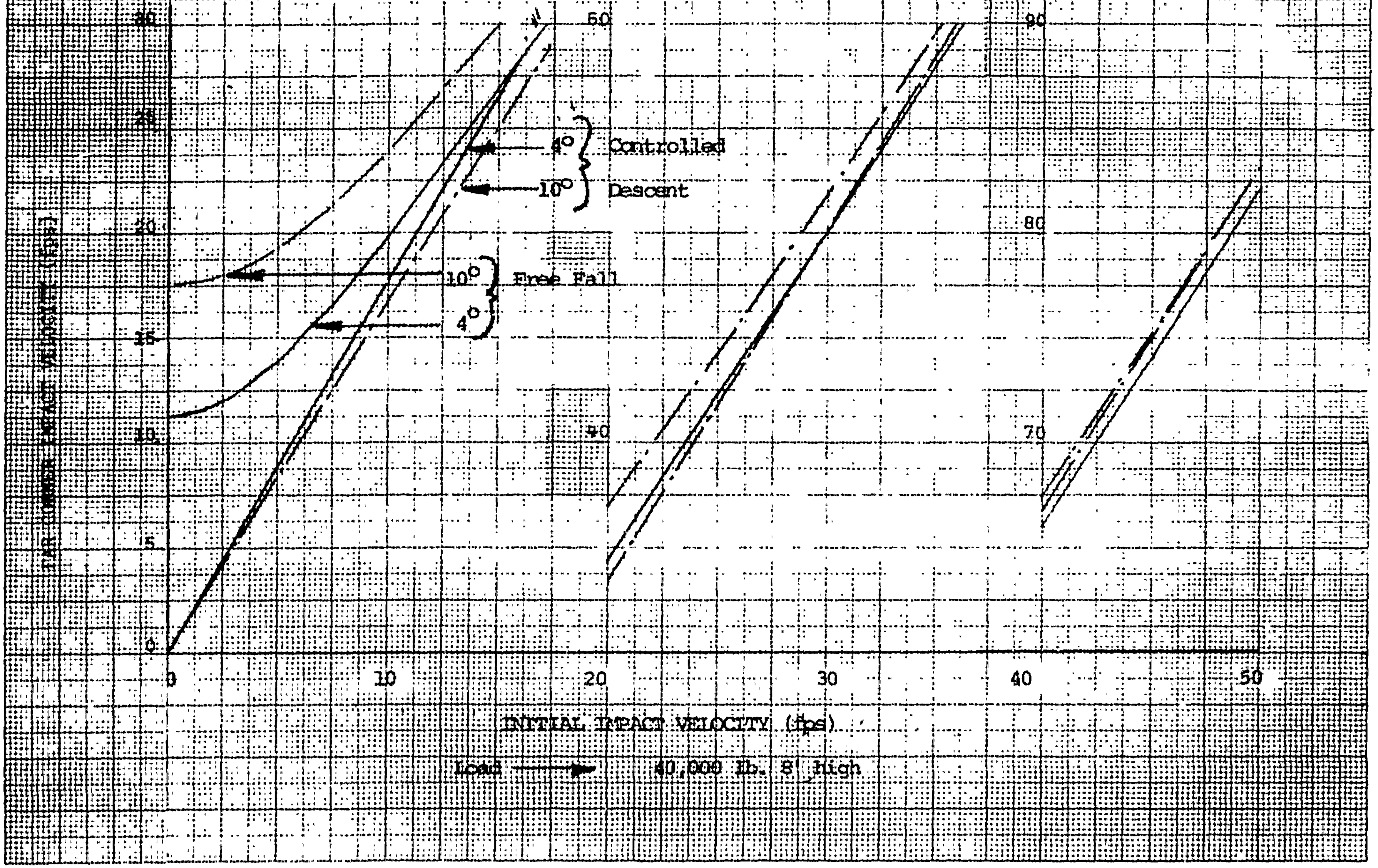
3. The low density free fall results are in better agreement with the controlled descent results than the high density free fall results.

4. Equivalency of the free fall method with the controlled descent method is achieved at a much lower initial impact velocity for the low density load than the high density load.

Although several of the observations made in this analysis relate to operating conditions beyond feasible levels, they serve to point out the relative differences and trends that exist between the free fall and controlled descent impacts. The velocity levels computed should also prove to be usable data. It is believed that true equivalence cannot be achieved between the two methods in practical initial impact velocity ranges. Final impact velocities in the free fall method can be made to agree with the controlled descent method if initial impact velocity and/or angle are appropriately modified.

FIGURE 1

FAR CORNER IMPACT VELOCITY VS INITIAL IMPACT VELOCITY AT DIFFERENT ANGLES



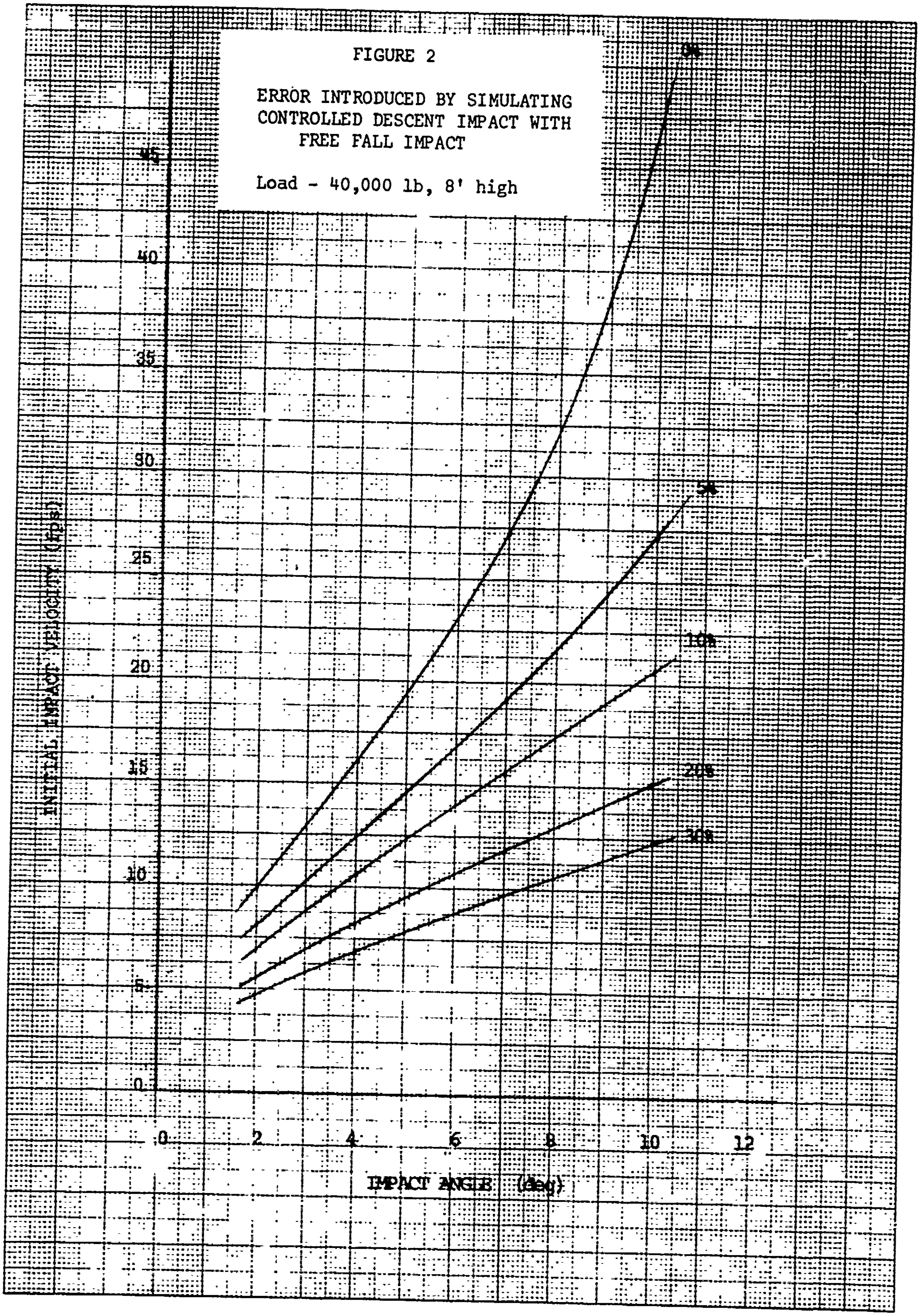
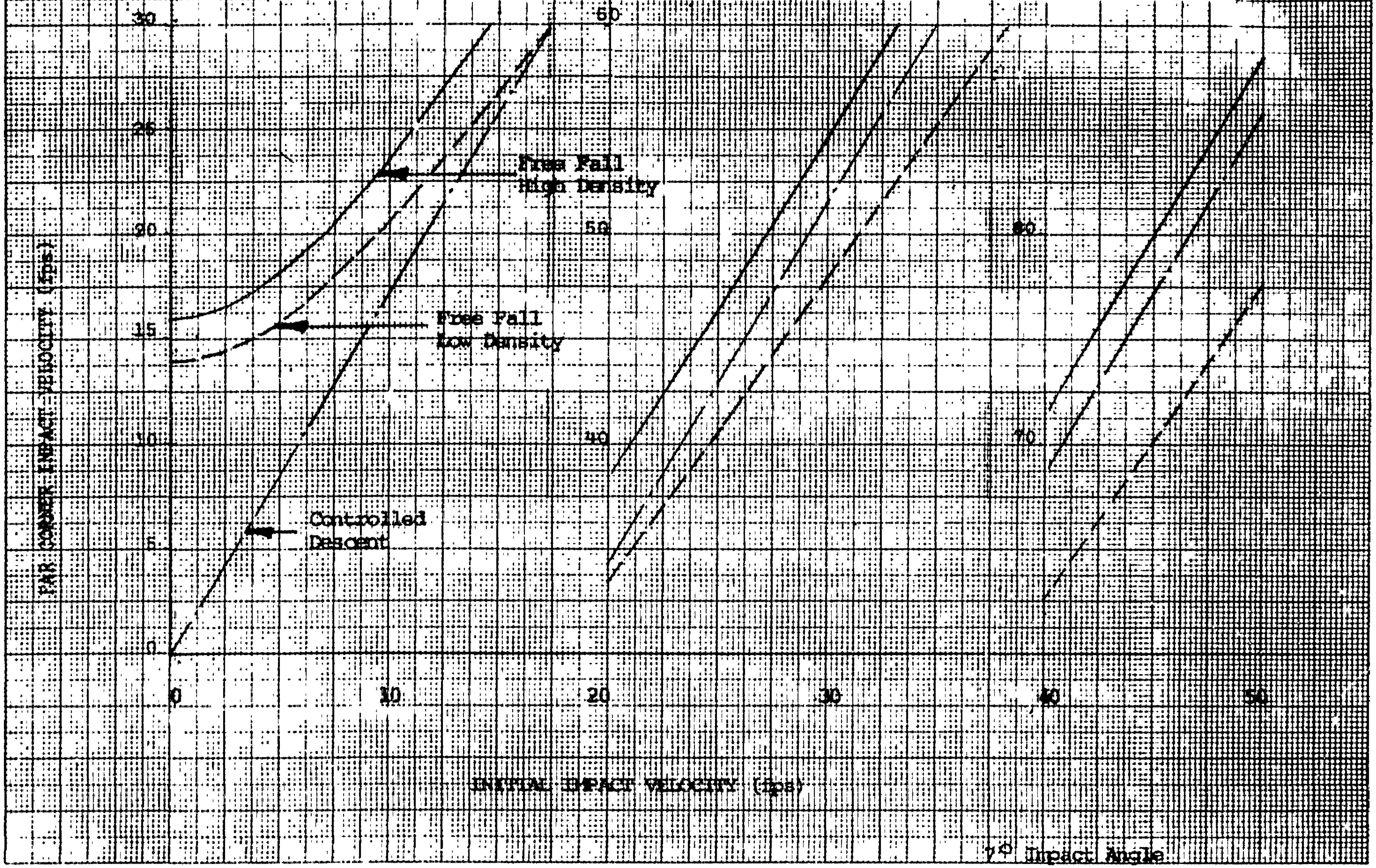


FIGURE 2

ERROR INTRODUCED BY SIMULATING CONTROLLED DESCENT IMPACT WITH FREE FALL IMPACT

Load - 40,000 lb, 8' high

FIGURE 3
FAR CORNER IMPACT VELOCITY VS INITIAL IMPACT VELOCITY AT DIFFERENT LOAD DENSITIES



DEFINITION OF SYMBOLS

NOMENCLATURE

m	mass of loaded container
v	initial impact velocity
W	weight of loaded container
h	c.g. elevation change due to rotation of container
I_A	moment of inertia of loaded container about A
ω	angular velocity of loaded container
K_A	radius of gyration of loaded container
V	tangential velocity of container base
r	distance from pivot to tangential velocity [illegible] point
g	acceleration of gravity (32.2 ft/s^2)
ϕ	impact angle
P	distance from pivot point to c.g. of loaded container
L	length of container
D	width of container
ψ	angle between P and container base
$\bar{y}$	perpendicular distance from container base to loaded c.g.
c	height of load
W_L	weight of load
H	height of container
W_C	weight of container
V_{TAN}	tangential velocity
V_T	controlled descent velocity
β	angle between V_T and V_{TAN}
P_T	distance from pivot to c.g. of container [illegible] (point [illegible])

I	moment of inertia of solid container about A
I_{CA}	moment of inertia of empty container about A
a, b, c	load dimensions

FREE FALL IMPACT

The energy expression at pos. 1 is

(1) $\frac{1}{2} mv^2 + Wh$

Assuming no slippage of corner A after impact, the resulting motion is pure rotation. The energy expression at position 3 is

(2) $\frac{1}{2} I_A \ \omega^2$

Equating (1) and (2) and solving for the angular velocity yields

(3) $\omega = \left[(mv^2 + 2Wh)/I_A\right]^{\frac{1}{2}}$

since $K_A = (I_A / m)^{\frac{1}{2}}$

and $\omega = V/r$

equation (3) becomes

$V/r = (v^2 + 2gh)^{\frac{1}{2}} / K_A$

solving for V yields

(4) $V = (v^2 + 2gh)^{\frac{1}{2}} \ r/K_A$

where

(5) $h = P \sin(\psi + \phi) - \bar{y}$

Assuming a homogeneous load

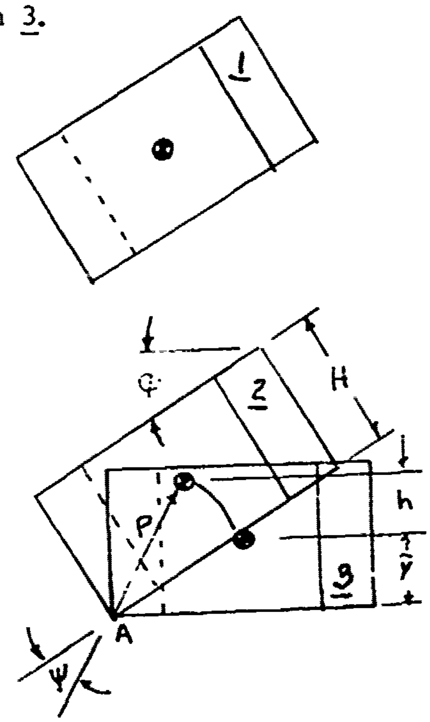
(6) $P = \left[(L/2)^2 + (D/2)^2 + \bar{y}^2\right]^{\frac{1}{2}}$

(7) $\psi = \sin^{-1} (\bar{y}/P)$

(8) $\bar{y} = (CW_L/2 + HWc/2)/W$

Using equations (6), (7), and (8) in equat. (5) will determine the elevation change of the center of gravity of the loaded container during its rotational phase from pos. 2 - 3.

Using equation (5) in equation (4) will allow the determination of the linear velocity at final impact position 3.



CONTROLLED DESCENT IMPACT

Assuming that the lowering cable is very long compared to the container's downward motion from position 2 to position 3, the cable remains vertical and the tangential velocity of point B in position 3 is given by

(9) $V_{TAN} = V_T / \cos \beta$

and container's angular velocity ω at position 3 is

(10) $\omega = V_{TAN} / P_T$

Substituting (9) into (10) gives

$\omega = V_T / P_T \cos \beta$

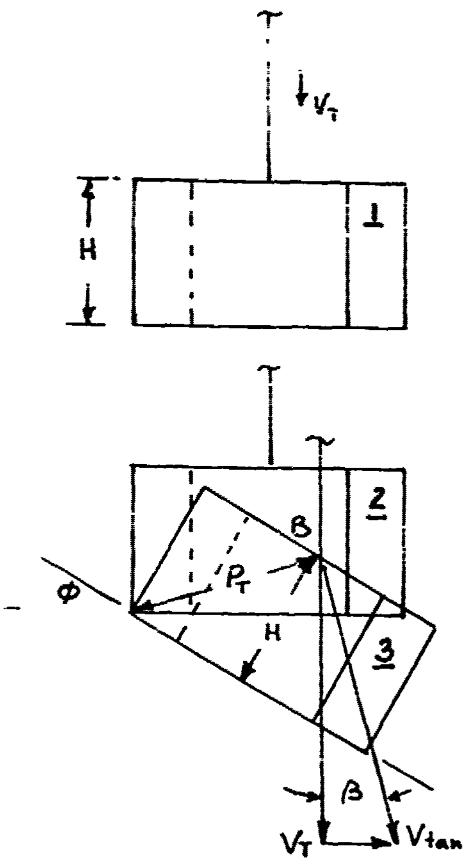
The velocity perpendicular to the container base in position 3 is

(11) $V = \omega r = r V_T / P_T \cos \beta$

where $P_T = \left[(L/2)^2 + (D/2)^2 + H^2 \right]^{1/2}$

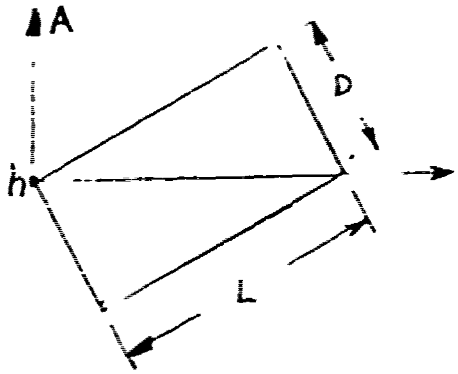
$\beta = (\sin^{-1} H/P_T) - \phi$

Note: It is assumed that no slippage of corner A occurs after impact.



CONTAINER MOMENT OF INERTIA

Consider a solid rectangular container having dimensions LxDxH on a right handed coordinate system B-A-h such that its base diagonal is along the B axis. Its moment of inertia about the A axis is given by the expression.



(12) $I = \int P_E^2 \, dm$

where

(13) $P_e^2 = (L^2 + D^2 + 4h^2)/4$

(14) $dm = (\rho LDdh)/g$

Substituting (13) and (14) into (12) gives

$I = \int_0^H (L^2 + D^2 + 4h^2)\rho \, LDdh/4g$

(15) $I = (L^2 + D^2 + 4H^2/3)\rho LDH/4g$

Given the following outside dimensions of the container:

H = 8', D = 8', L = 20'

and assuming that the container sides, ends, top, and bottom are 2 inches thick and homogeneous, the container volume is

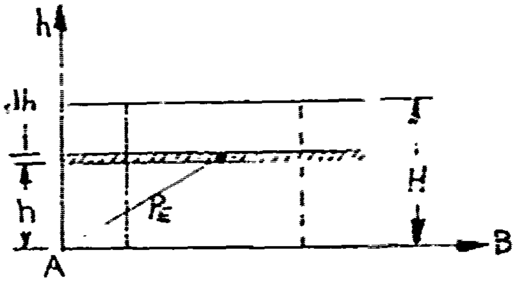
Vol = 8 X 8 X 20 - (7.667 X 7.667 X 19.667)

= 123.9 ft^3

For a 4000 lb. container the density is

ρ = 4000/123.9 = 32.28 pcf

The moment of inertia of the empty container can be written as the difference between the inertias of the solid container and the void given that they both have density of 32.28 pcf. From equation (15) I_{CA} = 24,415 slug ft^2



EFFECT OF LOAD ON MOMENT OF INERTIA

Considering loads of 20,000 lbs (½ container capacity) and 40,000 lbs. (container capacity), with heights (c) ranging from 2' to 8', homogenous weight characteristics and having base dimensions of axb, the following moments of inertia about the container pivot corner (A) and respective radii of gyration are computed.

Using equation (15) and I_{CA} = 24,415 slug ft^2

$$I_A = \left[(a^2 + b^2 + 4c^2/3)\ \rho abc/4g\right] + 24415$$

Recognizing that $\rho abc = W_L$

$$(16)\quad I_A = \left[(a^2 + b^2 + 4c^2/3)\ W_L/4g\right] + 24415$$

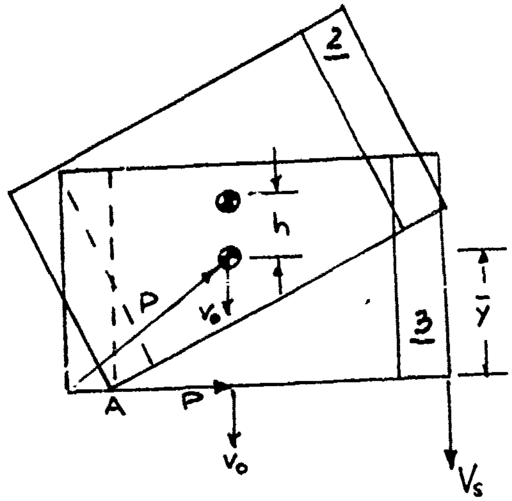
Using equation (16) with a = 19.667' and b = 7.667'

	20,000 lbs.		40,000 lbs.	
Load Height (c)	I_A	K_A	I_A	K_A
2	94,432	12.3	164,448	11.5
4	96,916	12.5	169,417	11.7
6	101,057	12.8	177,699	12.0
8	106,854	13.1	189,293	12.3

FREE FALL ANALYSIS
WITHOUT FRICTION

Energy at position 2 is

(17) $Wh + \frac{1}{2}mv^2$



Assuming a frictionless surface, corner A will slide back after impact in such a manner that the c.g. will move vertically downward. Translation and rotation are present. The energy relationship at position 3 is

(18) $\frac{1}{2} I_o\omega^2 + \frac{1}{2} mv_o^2$

where

I_o = moment of inertia about c.g.

v_o = vertical translation velocity of c.g.

equating (17) and (18), and noting that

$\omega = V_o/P_1$ because the vertical velocity of any point in the vertical plane through the c.g. must be equal to the vertical velocity of the c.g. if the body is rigid, yields

$$\frac{1}{2} I_o v_o^2/P_1^2 + \frac{1}{2} mv_o^2 = Wh + \frac{1}{2} mv^2$$

solving for v_o gives

(19) $v_o^2 = (2gh + v^2)\, m P_1^2/(I_o + m P_1^2)$

using $I_o = I_A - mP^2$

$I_o = m(K_A^2 - P^2)$

$-\bar{y}^2 = P_1^2 - P^2$

equation (19) becomes

(20) $v_o^2 = \left[(2gh + v^2)/(K_A^2 - \bar{y}^2)\right]^{\frac{1}{2}} P_1$

The velocity at any point on container is given by

(21) $V_s = rvo/P_1$

substituting (20) into (21) yields

(22) $V_s = \left[(2gh + v^2)/K_A^2 - \bar{y}^2)\right]^{\frac{1}{2}} r$

Comparing equation (22) which represents impact velocity assuming no friction at corner A with equation (4) which assumes sufficient friction at corner A to prevent slippage, we get:

(23) $V_s = \left[K_A V/(K_A^2 - \bar{y}^2)\right]^{\frac{1}{2}}$

This equation implies that Vs is always greater than V.

For the load ranges considered in the table of mass properties

$V_s = \alpha V$

Where α may have a value from 1.007 to 1.057.

APPENDIX C

M E M O R A N D U M

WH-8053-GJ:el
16 January 1978

From: G. Johnson (8053) *EL*
To: S. Petoia (8025)

Subj: Analysis of COTS Data

Encl: (1) COTS Data Analysis

1. In reply to your request COTS accelerometer test data was reviewed and analyzed. The results are attached as enclosure (1) for your information and retention.

2. The data were analyzed with respect to shock mitigation of the container and commodities by the use of padding, and optimal cushion density and thickness. An attempt was made to relate cumulative energy of impacts to container failure but there was insufficient data to formulate a relationship.

G. Johnson

G. JOHNSON

COTS Data Analysis

Enclosure (1)

From the data in Table 1 two scatter diagrams were drawn of g-level at the container corner fitting (channel 1) versus impact velocity for flat and corner drops to show the relationship between padded and unpadded shocks. It can be seen from Figures 1 and 2 that padding significantly lowers g-level response of the impact point. The presentation of scatter diagrams was selected because the data variation was of such a magnitude to preclude the generation of curves having reasonable confidence levels.

Another presentation of the shock data is given in Figure 3. Figure 3 is a histogram presentation of the percent mitigation in g-level between a padded and a bare drop under similar conditions of impact velocity, container type, load, and accelerometer, i.e.

percent mitigation = 100X (g bare-g padded)/g bare

The results of this computation are listed in Table 2 below the histogram. The histogram is a count of the number of comparisons which had a percent mitigation within the appropriate 5% range. Two significant results are evident from this presentation. The first is that the median value of this distribution is 71.4% - in other words, half of the events record greater than 71.4% mitigation using padding. The second fact is that the lower quintile value of the distribution is 50%, that is, 80% of the comparisons record at least 50% mitigation in g-level at the container corner fittings. It can be concluded that padding significantly effects container shock mitigation at the instrumented points. This does not directly imply that g-level is reduced at other parts of the container where dynamic response of the container structure will have a significant effect.

Two other points should be noted in regard to using the data to determine survivability. First, this type of padding may not be optimal. If Dow ETHAFOAM cushioning curves are investigated for the static stress range of 1 to 2 p.s.i. (half load to full load) the curves indicate that for an 18 inch drop (9.8 fps) a 5 inch thick cushion of 4 pcf density will result in lower g-levels than the 6 inches of 9 pcf foam used for these tests. The 4 pcf density prediction in this stress range is 12-15 g's, while the prediction for 9 pcf foam is 50-80 g's. Actually, the test data indicates that the 9 pcf foam resulted in g-levels between 20 and 40 g's. This discrepancy results from the flexural characteristics of the container which has the effect of increasing the static stress. The Dow literature indicates that the apparent static stress is 2-4 p.s.i. In this range five inches of 4 pcf density foam should yield a 12 g response.

The second point is that container survivability and commodity survivability are two different problems and must be addressed separately. The input shock to the container is caused by the foundation on which it is dropped and the input shock to the commodities is the pulse from the floor of the container. The rigid commodities did not experience a significant change in g-level between padded and unpadded drops so that the flooring must be responding to the lower frequencies input by the padded drop. Both drops show similar g-levels in the commodities and similar pulse durations of 30-40 ms which correspond to a 12-16 Hz natural frequency for the floor. If shock spectra on channel 1 or 2 from the padded impact (event 18) are compared to the bare impacts (event 27) at points 1 or 2 the result is shown in Figure 4. If the natural frequency of the

floor is 12-16 Hz as indicated by the response shock duration, the response will be 16-21 g's in the bare drop and 14-16 g's in the padded drop. The benefit due to this padding to the commodities during the impact is therefore predicted to be small. This is in agreement with the test data which shows no significant shock mitigation due to padding. If the flooring were stiffer or the padding softer the differences would be greater. If a detailed knowledge of the frequency response of the commodities were known, recommendations regarding floor stiffness and cushion density could be made.

Based on these results, the following is concluded:

(a) padding significantly lowers the g-level at the container corner fittings,

(b) because of the natural frequency of the container flooring, the flooring and therefore the rigid commodities on the floor were not significantly affected by the padding used, and

(c) a cushion density of 4 pounds per cubic foot, instead of the 9 pound per cubic foot foam used in the test, should lower commodity response significantly.

TABLE 1

COTS Container Drop Tests - Abstract Data Sheet

Drop No.	Nominal Velocity at Impact fps	G's Peak (Deceleration) Accelerometer Location 1	2	3	4	5	6
Container, All Steel (Mfg. by Strick); Load, None; Attitude; Flat; Surface, Padded							
1	4	9	22				
2	6	19	28				
3	8	31	37				
4	10	47	36				
Container, All Steel; Load, None; Attitude, Corner; Surface, Padded							
5	4	5	48				
6	6	9	47				
7	8	13	58				
8	10	16	59				
Container, All Steel; Load, None; Attitude, Flat; Surface, Bare							
9	4	34	13				
10	6	69	45				
11	8	75	50				
12	10	106	75				
Container, All Steel; Load, None; Attitude, Corner; Surface, Bare							
13	4	22	Inoperative				
14	6	63	"				
15	8	63	"				
16	10	88	"				
Container, All Steel; Load, 20,000#; Attitude, Flat; Surface,Padded							
17	4	13	10	8	7	15	18
18	6	25	19	16	11	21	22
19	8	34	28	18	17	25	27
20	10	-75	37	22	19	23	41
Container, All Steel; Load, 20,000#; Attitude, Corner; Surface, Padded							
21	4	5	22	5	12	19	29
22	6	9	28	7	12	23	28
23	8	13	34	9	18	27	29
24	10	22	49	10	14	29	28
25	10	72	-34	38	8	15	11

Drop No.	Nominal Velocity at Impact fps	G's Peak (Deceleration) Accelerometer Location 1	2	3	4	5	6
Container, All Steel; Load, 20,000#; Attitude, Flat; Surface, Bare							
26	4	50	34	8	10	18	12
27	6	66	47	9	15	20	12
28	8	88	75	15	14	27	22
29	10	81	96	20	19	36	22
Container, All Steel; Load, 20,000#; Attitude, Corner; Surface, Bare							
30	4	44	88	4	21	22	24
31	6	63	106	7	15	26	28
32	8	81	119	9	21	30	35
33	10	100	125	10	24	32	32
34	10	94	81	41	7	25	10
Container, Aluminum Panel (Mfg. by Theurer); Load, 40,000#; Attitude, Flat; Surface, Padded							
35	6	25	16	30	8	15	56
36	10	21	22	68	8	30	90
Container, Aluminum Panel; Load, 40,000#; Attitude, Corner; Surface, Padded							
37	6	9	31	40	12	11	24
38	10	21	63	80	10	21	106
Container, Aluminum Panel; Load, 40,000#; Attitude, Flat; Surface, Bare							
39	6	50	30	18	7	12	53
40	10	89	81	68	13	35	90
Container, Aluminum Panel; Load, 40,000#; Attitude, Corner; Surface, Bare							
41	6	44	125	32	12	7	88
42	10	100	109	140	14	20	105
Container, FRP (Mfg. by Theurer); Load, 40,000#; Attitude, Corner; Surface, Bare							
43	10	100	150	20	12	12	110
Container, FRP; Load, 40,000#; Attitude, Flat; Surface, Bare							
44	10	81	88	80	8	58	48

NOTE: Accelerometer Location: #1 and 2 were external and at diagonal corner fittings throughout; #1 was at the door end and was initially impacted corner in corner drops except for drops 25 and 34. For these two drops, #2 accelerometer received the initial impact. #3 and #4 were located on test load modules inside the container corresponding to #'s 1 and 2; #5 and #6 were on palletized test modules, throughout 20,000# drops. These locations were changed for 40,000# drops. #4 and 5 were at the door end, and #3 and #6 were at the closed end. All four were placed atop the upper tier.

FIGURE 1

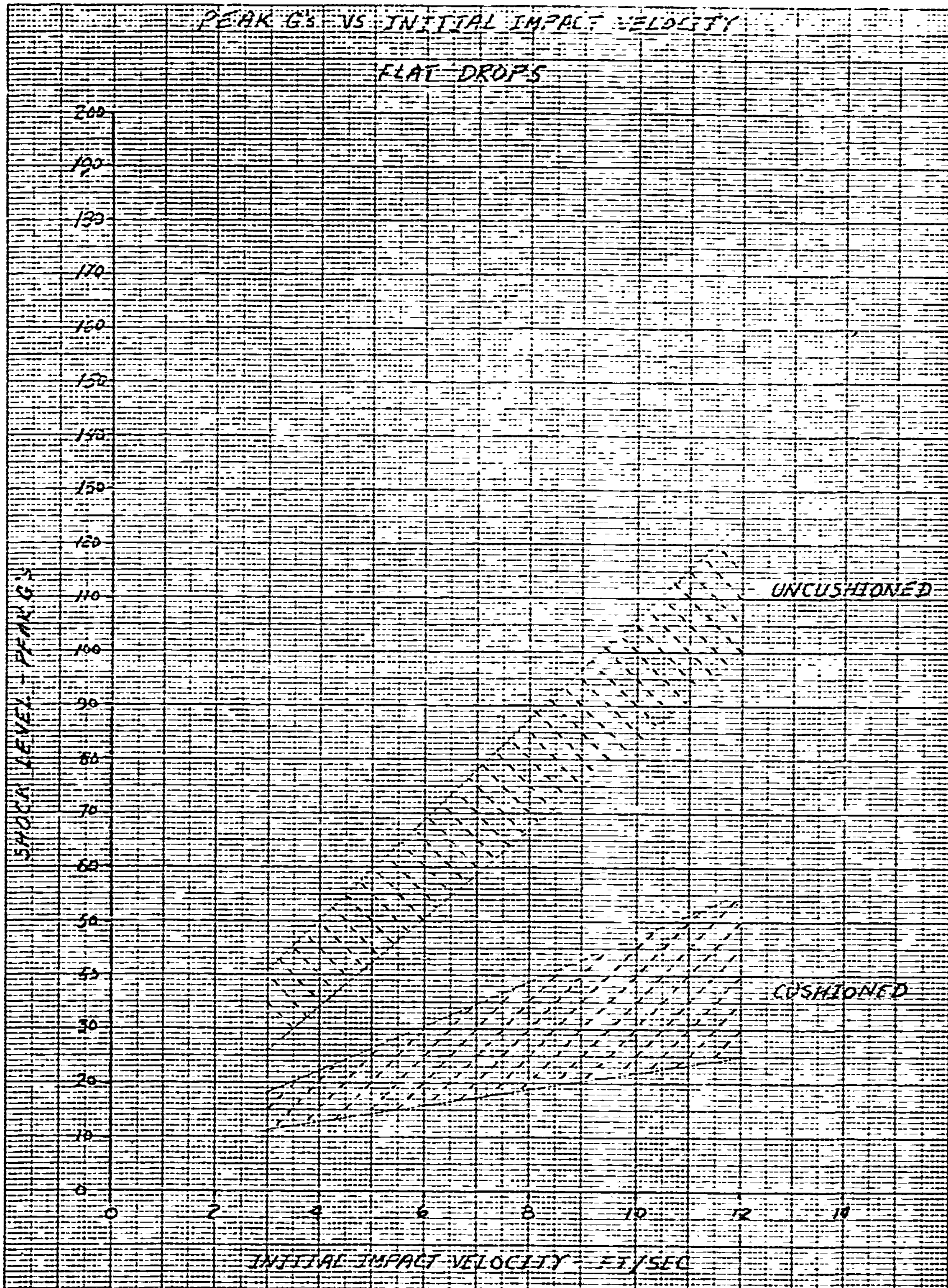

PEAK G's VS INITIAL IMPACT VELOCITY
FLAT DROPS
SHOCK LEVEL - PEAK G's
INITIAL IMPACT VELOCITY - FT/SEC
UNCUSHIONED
CUSHIONED
0
2
4
6
8
10
12
14

FIGURE 2

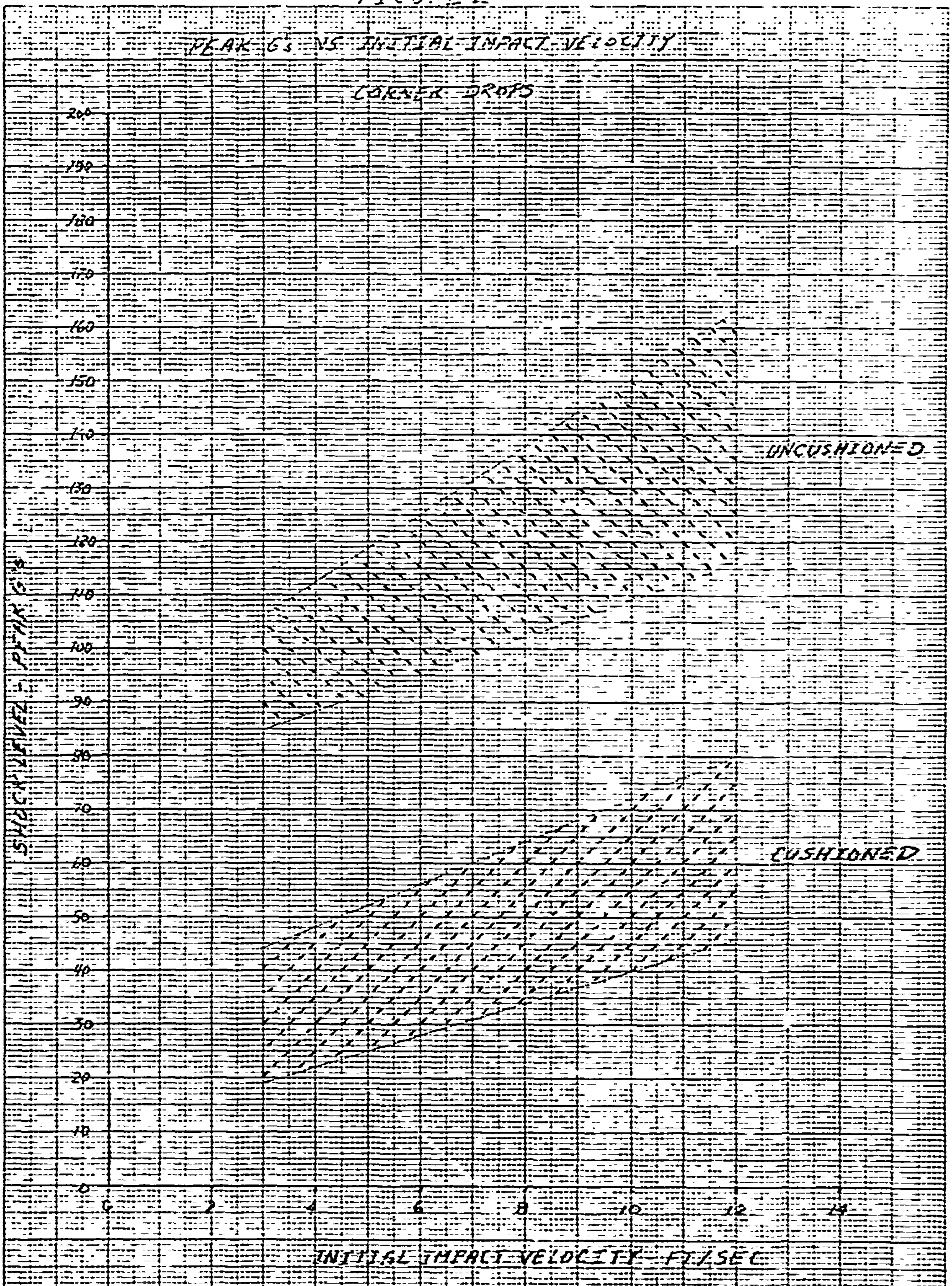


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Figure 3
Percent Mitigation of Shocks by Cushioning
(Compared to Bare Impact)

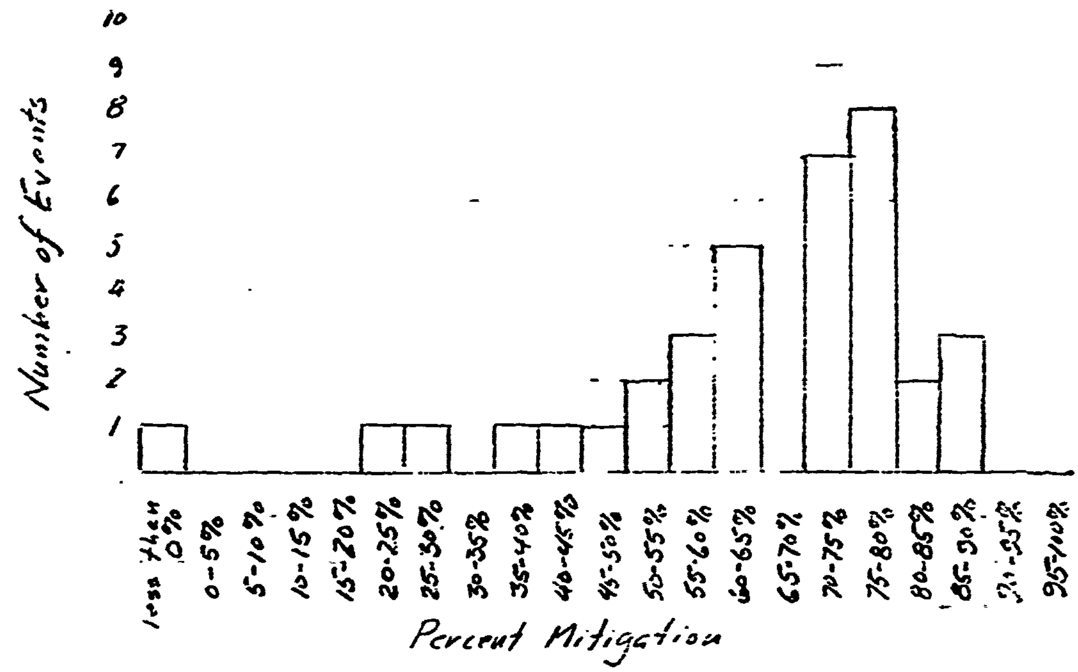

Table 2
Table of Data Used for Above Histogram

Test Event Nos. Compared: Cushioned	Test Event Nos. Compared: Bare	% Mitigation: Accelerometer 1	% Mitigation: Accelerometer 2
1	9	73.5%	-69.2%
2	10	72.5%	37.8%
3	11	58.7%	26.0%
4	12	55.7%	52.0%
5	13	77.2%	—
6	14	85.7%	accelerometer inoperative
7	15	79.4%	
8	16	81.8%	—
17	26	74.0%	70.6%
18	27	62.1%	59.6%
19	28	61.4%	62.7%
20	29	—	61.5%
21	30	88.6%	75.0%
22	31	85.7%	73.6%
23	32	84.0%	71.4%
24	33	78.0%	60.8%
25	34	23.4%	—
35	39	50.0%	46.7%
36	40	76.4%	72.8%
37	41	79.5%	75.2%
38	42	79.0%	42.2%

Note: negative g-levels not used in mitigation calculations

DATE 077356 REMARKS FIGURE.4

SHOCK SPECTRUM
UNPADDED = *
PADDED = +

FREQ HZ	UNPAD G	PAD G
1.	1.3	1.2
2.	2.7	2.4
3.	4.0	3.6
4.	5.4	4.8
5.	6.7	6.0
7.	9.3	8.3
9.	12.0	10.5
11.	14.6	12.5
13.	17.1	14.3
15.	19.6	15.5
17.	22.1	15.6
19.	24.4	15.1
21.	26.8	17.0
23.	29.0	18.9
25.	31.1	20.5
30.	35.9	24.2
35.	39.5	27.4
40.	42.1	28.7
45.	44.6	28.5
50.	49.4	48.7
55.	53.1	67.5
60.	55.2	73.1
65.	57.0	81.1
70.	62.2	84.9
75.	66.8	79.2